A HEPATITIS C VIRUS NON-STRUCTURAL NS3/4A FUSION GENE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application Nos. 60/225,767 and 60/229,175, filed August 17, 2000 and August 29, 2000, respectively, and U.S. Patent Application No. 09/705,547, filed November 3, 2000, all of which are hereby expressly incorporated by reference in their entireties.

FIELD OF THE INVENTION

The present invention relates to the discovery of a novel hepatitis C virus (HCV) isolated from a human patient. Embodiments include novel HCV peptides, nucleic acids encoding said HCV peptides, antibodies directed to said peptides, compositions containing said nucleic acids and peptides, as well as methods of making and using the aforementioned compositions including, but not limited to, diagnostics and medicaments for the treatment and prevention of HCV infection.

BACKGROUND OF THE INVENTION

Viruses are intracellular parasites that require the biochemical machinery of a host cell for replication and propagation. All virus particles contain some genetic information that encodes viral structural proteins and enzymes. The genetic material may be DNA or RNA, in double- or single stranded form. (Virology, Fields ed., third edition, Lippencott-Raven publishers, pp 72-83 (1996)). The viral nucleic acid is surrounded by a coat of proteins called the capsid. (*Id.*) In some viruses the capsid is surrounded by an additional layer comprised of a lipid membrane, referred to as the envelope. (*Id.* at 83-95).

The typical viral life cycle begins with infection of a host cell through attachment of the virus particle to a cell surface receptor and internalization of the viral capsid. (*Id.* at 103). Accordingly, a virus' host range is limited to cells that express an appropriate cell surface receptor. Once internalized, the virus particle is disassembled and its nucleic acid is transcribed, translated or replicated. (*Id.*) At this point, the virus

may undergo lytic replication, where new virus particles are formed and released from the infected cell. (*Id.* at 105-11). The Influenza virus is a typical example of a virus that undergoes lytic replication immediately upon infection of a host cell. (*Id.* at 1369-85).

Alternatively, a virus may enter a latent phase, referred to as lysogeny, where the genome is replicated but few if any viral proteins are actually expressed and viral particles are not formed. (*Id.* at 219-29). Herpesviruses such as the Epstein-Barr Virus are typical examples of viruses that establish latent infection in the host cells. (*Id.* at 229-34). Eventually, in order for the virus to spread, it must exit lysogeny and enter the lytic phase. The viral particles that are released during the lytic phase infect other cells of the same individual or can be transmitted to another individual where a new infection is established.

Since the viral life cycle comprises both an intracellular and extracellular phase, both the humoral and cell-mediated immune defense systems are important for combating viral infections. (*Id.* at 467-73). Antibodies directed against viral proteins may block the virus particle's interaction with its cellular receptor or otherwise interfere with the internalization or release processes. (*Id.* at 471). An antibody capable of interfering with the viral life cycle is referred to as a neutralizing antibody.

During intracellular replication, viral proteins, which are foreign to the host cell, are produced and some of these proteins are digested by cellular proteases after coupling to a Major Histocompatibility Complex (MHC) molecule presented on the surface of the infected cell. (*Id.* at 350-58). Thus, the infected cell is recognized by T-lymphocytes, macrophages or NK-cells and killed before the virus replicates and spreads to adjacent cells. (*Id.* at 468-70). In addition, the presence of viral nucleic acids, most notably as double-stranded RNA, triggers the infected cell to shut down its translation machinery and to produce antiviral signaling molecules known as interferons. (*Id.* at 376-79).

Viruses have evolved various means of evading the immune defense system of the host, however. By establishing latency (i.e., lysogeny), for example, the virus does not enter the lytic phase and avoids the humoral immune defense system. (*Id.* at 224). During the latent phase, few viral proteins are produced and infected cells have only a minimal ability to present evidence to surrounding lymphocytes and macrophages of their infected state. (*Id.* at 225-26). Additionally, some viral proteins, most notably

those produced during latency, evolve polypeptide sequences that cannot be efficiently presented to the cell mediated immune defense system. (Levitskaya *et al.*, *Nature* 375:685-88 (1995)). Finally, some viruses may actively interfere with the immune response of the infected host, for instance by preventing surface expression of MHC molecules (Fruh *et al.*, *J. Mol. Med.* 75:18-27 (1997)), or by disrupting interferon signaling (Fortunato *et al.*, *Trends Microbiol.* 8:111-19 (2000)).

Particularly evasive are the hepatitis viruses, which are not classified as a family but are grouped based on their ability to infect cells of the liver. Hepatitis C Virus (HCV) belongs to the *Flaviviridae* family of single-stranded RNA viruses. (Virology, Fields ed., third edition, Lippencott-Raven publishers, pp 945-51 (1996)). The HCV genome is approximately 9.6 kb in length, and encodes at least ten polypeptides. (Kato, *Microb. Comp. Genomics*, 5:129-151 (2000)). The genomic RNA is translated into one single polyprotein that is subsequently cleaved by viral and cellular proteases to yield the functional polypeptides. (*Id.*) The polyprotein is cleaved to three structural proteins (core protein, E1 and E2), to p7 of unknown function, and to six non-structural (NS) proteins (NS2, NS3, NS4A/B, NS5A/B). (*Id.*) NS3 encodes a serine protease that is responsible for some of the proteolytic events required for virus maturation (Kwong *et al.*, *Antiviral Res.*, 41:67-84 (1999)) and NS4A acts as a co-factor for the NS3 protease. (*Id.*) NS3 further displays NTPase activity, and possesses RNA helicase activity *in vitro*. (Kwong *et al.*, *Curr. Top. Microbiol. Immunol.*, 242:171-96 (2000)).

HCV infection typically progresses from an acute to a chronic phase. (Virology, Fields ed., third edition, Lippencott-Raven publishers, pp 1041-47 (1996)). Acute infection is characterized by high viral replication and high viral load in liver tissue and peripheral blood. (*Id.* at 1041-42.) The acute infection is cleared by the patient's immune defense system in roughly 15% of the infected individuals; in the other 85% the virus establishes a chronic, persistent infection. (Lawrence, *Adv. Intern. Med.*, 45:65-105 (2000)). During the chronic phase replication takes place in the liver, and some virus can be detected in peripheral blood. (Virology, Fields ed., third edition, Lippencott-Raven publishers, pp 1042 (1996)).

Essential to the establishment of a persistent infection is the evolution of strategies for evading the host's immune defense system. HCV, as a single stranded

RNA virus, displays a high mutation rate in the replication and transcription of its genome. (*Id.* at 1046). Thus, it has been noted that the antibodies produced during the lytic phase seldom neutralize virus strains produced during chronic infection. (*Id.*) Although it appears HCV is not interfering with antigen processing and presentation on MHC-I molecules, the viral NS5A protein may be involved in repression of interferon signaling through inhibition of the PKR protein kinase. (Tan *et al.*, *Virology*, 284:1-12 (2001)).

The infected host mounts both a humoral and a cellular immune response against the HCV virus but in most cases the response fails to prevent establishment of the chronic disease. Following the acute phase, the infected patient produces antiviral antibodies including neutralizing antibodies to the envelope proteins E1 and E2. (*Id.* at 1045). This antibody response is sustained during chronic infection. (*Id.*) In chronically infected patients, the liver is also infiltrated by both CD8+ and CD4+ lymphocytes. (*Id.* at 1044-45). Additionally, infected patients produce interferons as an early response to the viral infection. (*Id.* at 1045). It is likely that the vigor of the initial immune response against the infection determines whether the virus will be cleared or whether the infection will progress to a chronic phase. (Pape *et al.*, *J. Viral. Hepat.*, 6 Supp. 1:36-40 (1999)). Despite the efforts of others, the need for efficient immunogens and medicaments for the prevention and treatment of HCV infection is manifest.

SUMMARY OF THE INVENTION

A new HCV sequence was discovered. A novel NS3/4A fragment of the HCV genome was cloned and sequenced from a patient infected with HCV (**SEQ. ID. NO.: 1**). This sequence was found to be only 93% homologous to the most closely related HCV sequence. Embodiments include this novel peptide (**SEQ. ID. NO.: 2**) and fragments thereof at least 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length, nucleic acids encoding these molecules, vectors having said nucleic acids, and cells having said vectors, nucleic acids, or peptides. The NS3/4A nucleic acid, fragments thereof and corresponding peptides are immunogenic. Accordingly, preferred embodiments include vaccine compositions comprising the HCV peptide of **SEQ. ID. NO.: 2** or a fragment

thereof at least 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length (e.g., **SEQ. ID. NOs.: 14 and 15**) or a nucleic acid encoding said peptide or fragments.

Mutants of the NS3/4A peptide were also created. Some mutants are truncated versions of the NS3/4A peptide (e.g., **SEQ. ID. NOs.: 12 and 13**) and others lack a proteolytic cleavage site (e.g., **SEQ. ID. NOs.: 3-11**). These molecules and the nucleic acids encoding them are also immunogenic. These novel peptides **(SEQ. ID. NOs.: 3-13)** and fragments thereof at least 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length (e.g., **SEQ. ID. NOs.: 15-26**), nucleic acids encoding these molecules, vectors having said nucleic acids, and cells having said vectors, nucleic acids, or peptides are embodiments of the invention. A particularly preferred embodiment is a vaccine composition comprising at least one HCV peptide of **SEQ. ID. NOs.: 3-11** or a fragment thereof at least 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length (e.g., **SEQ. ID. NOs.: 16-26**) or a nucleic acid encoding said peptides or fragments.

Methods of making and using the compositions described herein are also embodiments of the invention. In addition to methods of making the embodied nucleic acids and peptides, other embodiments include methods of making vaccine compositions that can be used to treat or prevent HCV infection. Some methods are practiced, for example, by mixing an adjuvant with a peptide or nucleic acid antigen (e.g., an HCV peptide or HCV nucleic acid, as described above so as to formulate a single composition (e.g., a vaccine composition). Preferred methods involve the mixing of ribavirin with an HCV gene or antigen disclosed herein.

Preferred methods of using the compositions described herein involve providing an animal in need of a potent immune response to HCV with a sufficient amount of one or more of the nucleic acid or peptide embodiments described herein. By one approach, for example, an animal in need of potent immune response to HCV (e.g., an animal at risk or already infected with HCV) is identified and said animal is provided an amount of NS3/4A (**SEQ. ID. NO.: 2**), a mutant NS3/4A (**SEQ. ID. NOs.: 3-13**), a fragment thereof (e.g., **SEQ. ID. NOs.: 14-26**) or a nucleic acid encoding said molecules that is effective to enhance or facilitate an immune response to the hepatitis viral antigen. Additional methods are practiced by identifying an animal in need of a potent immune response to HCV and providing said animal a composition comprising a peptide

comprising an antigen or epitope present on **SEQ. ID. NOs.: 2-27** or a nucleic acid encoding said peptide. Particularly preferred methods involve the identification of an animal in need of an potent immune response to HCV and providing said animal a composition comprising an amount of HCV antigen (e.g., NS3/4A (**SEQ. ID. NO.: 2**)), mutant NS3/4A (**SEQ. ID. NOs.: 3-13**), a fragment thereof at least 3, 4-10, 10-20, 20-30, 30-50 amino acids in length (e.g., **SEQ. ID. NOs.: 14-26**) or a nucleic acid encoding one or more of these molecules) that is sufficient to enhance or facilitate an immune response to said antigen. In some embodiments, the composition described above also contains an amount of ribavirin that provides an adjuvant effect.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a graph showing the antibody titer in H-2^d mice against NS3 as a function of time after the first immunization. Diamonds denote antibody titer in mice immunized with NS3/4A-pVAX and squares denote antibody titer in mice immunized with NS3-pVAX.

FIGURE 2A is a graph showing the percentage of specific CTL-mediated lysis of SP2/0 target cells as a function of the effector to target ratio. Phosphate Buffered Saline (PBS) was used as a control immunogen.

FIGURE 2B Is a graph showing the percentage specific CTL-mediated lysis of SP2/0 target cells as a function of the effector to target ratio. Plasmid NS3/4A-pVAX was used as the immunogen.

FIGURE 3 is a graph showing the humoral response to 10 and 100μg recombinant Hepatitis C virus (HCV) non structural 3 protein (NS3), as determined by mean end point titres, when a single dose of 1mg of ribavirin was co-administered.

FIGURE 4 is a graph showing the humoral response to 20μg recombinant Hepatitis C virus (HCV) non structural 3 protein (NS3), as determined by mean end point titres, when a single dose of 0.1, 1.0, or 10mg of ribavirin was co-administered.

FIGURE 5 is a graph showing the effects of a single dose of 1mg ribavirin on NS3-specific lymph node proliferative responses, as determined by *in vitro* recall responses.

DETAILED DESCRIPTION OF THE INVENTION

A novel nucleic acid and protein corresponding to the NS3/4A domain of HCV was cloned from a patient infected with HCV (**SEQ. ID. NO.: 1**). A Genebank search revealed that the cloned sequence had the greatest homology to HCV sequences but was only 93% homologous to the closest HCV relative (accession no AJ 278830). This novel peptide (**SEQ. ID. NO.: 2**) and fragments thereof at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 14 and 15**), nucleic acids encoding these molecules, vectors having said nucleic acids, and cells having said vectors, nucleic acids, or peptides are embodiments of the invention.

Mutants of the novel NS3/4A peptide were created. It was discovered that truncated mutants (e.g., **SEQ. ID. NOs.: 12 and 13**) and mutants that lack a proteolytic cleavage site (**SEQ. ID. NOs.: 3-11**), are highly immunogenic. These novel peptides (**SEQ. ID. NOs.: 3-13**) and fragments thereof at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 16-26**), nucleic acids encoding these molecules, vectors having said nucleic acids, and cells having said vectors, nucleic acids, or peptides are also embodiments of the invention.

The peptides and nucleic acids described above are useful as immunogens, which can be administered alone or in conjunction with an adjuvant. Preferred embodiments include compositions that comprise one or more of the nucleic acids and/or peptides described above and an adjuvant. That is, some of the vaccine embodiments described herein comprise an adjuvant and the novel NS3/4A peptide (**SEQ. ID. NO.: 2**) or a fragment thereof at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 14 and 15**) or a nucleic acid encoding one or more of these molecules. Additional vaccine embodiments comprise an adjuvant and one or more of the NS3/4A mutant peptides (**SEQ. ID. NOs.: 3-13**) or a fragment thereof at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 16-26**) or a nucleic acid encoding one or more of these molecules.

It was also discovered that compositions comprising ribavirin and an antigen (e.g., a molecule containing an epitope of a pathogen such as a virus, bacteria, mold, yeast, parasite) enhance and/or facilitate an animal's immune response to the antigen.

That is, it was discovered that ribavirin is a very effective "adjuvant," which for the purposes of this disclosure, refers to a material that has the ability to enhance or facilitate an immune response to a particular antigen. The adjuvant activity of ribavirin was manifested by a significant increase in immune-mediated protection against the antigen, an increase in the titer of antibody raised to the antigen, and an increase in proliferative T cell responses.

Accordingly, compositions (e.g., vaccines and other medicaments) that comprise ribavirin and one or more of the peptides or nucleic acids described herein are embodiments. These compositions can vary according to the amount of ribavirin, the form of ribavirin, as well as the sequence of the HCV nucleic acid or peptide.

Also embodied are methods of making and using the compositions above. Some methods involve the making of nucleic acids encoding NS3/4A, mutant NS34A, fragments thereof at least 9-30 consecutive nucleotides in length (e.g., 9, 12, 15, 18, 21, 24, 27, or 30 consecutive nucleotides in length), peptides corresponding to said nucleic acids, constructs comprising said nucleic acids, and cells containing said compositions. Preferred methods, however, concern the making of vaccine compositions comprising the newly discovered NS3/4A fragment or an NS3/4A mutant (e.g., a truncated mutant or a mutant lacking a proteolytic cleavage site), or a fragment thereof of at least three amino acids in length or a nucleic acid encoding one or more of these molecules. Preferred fragments for use with the methods described herein include **SEQ. ID. NOs.: 12-27**. The compositions described above can be made by providing an adjuvant (e.g., ribavirin), providing an HCV antigen (e.g., a peptide comprising an HCV antigen such as (**SEQ. ID. NOs.: 2-11**) or a fragment thereof such as, **SEQ. ID. NOs.: 12-26** or a nucleic acid encoding one or more of said peptides), and mixing said ribavirin and said HCV antigen so as to formulate a composition that can be used to enhance or facilitate an immune response in a subject to said antigen.

Methods of enhancing or facilitating the immune response of an animal, including humans, to an antigen are also desired. Such methods can be practiced, for example, by identifying an animal in need of a potent immune response to HCV and providing said animal a composition comprising one or more of the nucleic acids or peptides above and an amount of adjuvant (e.g., ribavirin) that is effective to enhance or

facilitate an immune response to the antigen/epitope. In some embodiments, the antigen and the adjuvant are administered separately, instead of in a single mixture. Preferably, in this instance, the ribavirin is administered a short time before or a short time after admininstering the antigen. Preferred methods involve providing the animal in need with ribavirin and NS3/4A (e.g., **SEQ. ID. NO.: 2**), a mutant NS3/4A (e.g., **SEQ. ID. NOs.: 3-13**), a fragment thereof of at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 14-26**) or a nucleic acid encoding said molecules.

Other embodiments of the invention concern methods of treating and preventing HCV infection. By one approach, an immunogen comprising one or more of the HCV nucleic acids or peptides described herein are used to prepare a medicament for the treatment and/or prevention of HCV infection. By another approach, an individual in need of a medicament that prevents and/or treats HCV infection is identified and said individual is provided a medicament comprising ribavirin and an HCV antigen such as NS3/4A (e.g., **SEQ. ID. NO.: 2**) or a mutant NS3/4A (e.g., **SEQ. ID. NOs.: 3-13**), a fragment thereof of at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 14-26**) or a nucleic acid encoding one or more of these molecules. The section below discusses the discovery of the novel NS3/4A, the creation of NS3/4A mutants, and the characterization of these nucleic acids and peptides corresponding thereto.

NS3/4A and NS3/4A mutants

A novel nucleic acid and protein corresponding to the NS3/4A domain of HCV was cloned from a patient infected with HCV (**SEQ. ID. NOs.: 1 and 2**). A Genebank search revealed that the cloned sequence had the greatest homology to HCV sequences but was only 93% homologous to the closest HCV relative (accession no AJ 278830). A truncated mutant of the novel NS3/4A peptide and NS3/4A mutants, which lack a proteolytic cleavage site, were also created. It was discovered that these novel peptides and nucleic acids encoding said peptides were potent immunogens that can be mixed with adjuvants (e.g., ribavirin) so as to make a composition that provides a recipient

with a potent immune response to HCV. The cloning of the novel NS3/4A domain and the creation of the various NS3/4A mutants are described in the following example.

EXAMPLE 1

The NS3/4A sequence was amplified from the serum of an HCV-infected patient (HCV genotype 1a) using the Polymerase Chain Reaction (PCR). Total RNA was extracted from serum, and cDNA synthesis and PCR were performed according to standard protocols (Chen M et al., *J. Med. Virol.* 43:223-226 (1995), herein expressly incorporated by reference in its entirety). The cDNA synthesis was initiated using the antisense primer "NS4KR" (5'-CCG TCT AGA TCA GCA CTC TTC CAT TTC ATC-3' (**SEQ. ID. NO.: 28**)). From this cDNA, a 2079 base pair DNA fragment of HCV, corresponding to amino acids 1007 to 1711, which encompasses the NS3 and NS4A genes, was amplified. A high fidelity polymerase (Expand High Fidelity PCR, Boehringer-Mannheim, Mannheim, Germany) was used with the "NS3KF" primer (5'-CCT GAA TTC ATG GCG CCT ATC ACG GCC TAT-3' (**SEQ. ID. NO.: 29**) and the NS4KR primer. The NS3KF primer contained a *EcoRI* restriction enzyme cleavage site and a start codon and the primer NS4KR contained a *XbaI* restriction enzyme cleavage site and a stop codon.

The amplified fragment was then sequenced (**SEQ. ID. NO.: 1**). Sequence comparison analysis revealed that the gene fragment was indeed amplified from a viral strain of genotype 1a. A computerized BLAST search against the Genbank database using the NCBI website revealed that the closest HCV homologue was 93% identical in nucleotide sequence.

The amplified DNA fragment was then digested with *EcoRI* and *XbaI*, and was inserted into a pcDNA3.1/His plasmid (Invitrogen) digested with the same enzymes. The NS3/4A-pcDNA3.1 plasmid was then digested with *EcoRI* and *Xba I* and the insert was purified using the QiaQuick kit (Qiagen, Hamburg, Germany) and was ligated to a *EcoRI/Xba I* digested pVAX vector (Invitrogen) so as to generate the NS3/4A-pVAX plasmid.

The rNS3 truncated mutant was obtained by deleting NS4A sequence from the NS3/4A DNA. Accordingly, the NS3 gene sequence of NS3/4A-pVAX was PCR

amplified using the primers NS3KF and 3'*NotI* (5'-CCA CGC GGC CGC GAC GAC CTA CAG-3' (**SEQ. ID. NO.: 30**)) containing *EcoRI* and *Not I* restriction sites, respectively. The NS3 fragment (1850 bp) was then ligated to a *EcoRI* and *Not I* digested pVAX plasmid to generate the NS3-pVAX vector. Plasmids were grown in BL21 *E.coli* cells. The plasmids were sequenced and were verified by restriction cleavage and the results were as to be expected based on the original sequence.

TABLE 1 describes the sequence of the proteolytic clevage site of NS3/4A, referred to as the breakpoint between NS3 and NS4A. This wild-type breakpoint sequence was mutated in many different ways so as to generate several different NS3/4A breakpoint mutants. **TABLE 1** also identifies these mutant breakponit sequences. The fragments listed in **TABLE 1** are preferred immunogens that can be incorporated with or without an adjuvant (e.g., ribavirin) into a composition for administration to an animal so as to induce an immune response in said animal to HCV.

To change the proteolytic cleavage site between NS3 and NS4A, the NS3/4A-pVAX plasmid was mutagenized using the QUICKCHANGE™ mutagenesis kit (Stratagene), following the manufacturer's recommendations. To generate the "TPT" mutation, for example, the plasmid was amplified using the primers 5′-CTGGAGGTCGTCACGCCTACCTGGGTGCTCGTT-3′ (**SEQ. ID. NO.: 31**) and 5′-ACCGAGCACCCAGGTAGGCGTGACGACCTCCAG-3′ (**SEQ. ID. NO.: 32**) resulting in NS3/4A-TPT-pVAX. To generate the "RGT" mutation, for example, the plasmid was amplified using the primers 5′-CTGGAGGTCGTCCGCGGTACCTGGGTGCTCGTT-3′ (**SEQ. ID. NO.: 33**) and 5′-ACCGAGCACCCAGGTACC-GCGGACGACCTCCAG-3′ (**SEQ. ID. NO.: 34**) resulting in NS3/4A-RGT-pVAX.

All mutagenized constructs were sequenced to verify that the mutations had been correctly made. Plasmids were grown in competent BL21 E. coli. The plasmid DNA used for *in vivo* injection was purified using Qiagen DNA purification columns, according to the manufacturers instructions (Qiagen GmbH, Hilden, FRG). The concentration of the resulting plasmid DNA was determined spectrophotometrically (Dynaquant, Pharmacia Biotech, Uppsala, Sweden) and the purified DNA was dissolved in sterile phosphate buffer saline (PBS) at concentrations of 1 mg/ml.

TABLE 1

Plasmid	Deduced amino acid sequence
*NS3/4A-pVAX	TKYMTCMSADLEVVTSTWVLVGGVL **(SEQ. ID. NO.: 14)**
NS3/4A-TGT-pVAX	TKYMTCMSADLEVVTGTWVLVGGVL **(SEQ. ID. NO.: 16)**
NS3/4A-RGT-pVAX	TKYMTCMSADLEVVRGTWVLVGGVL **(SEQ. ID. NO.: 17)**
NS3/4A-TPT-pVAX	TKYMTCMSADLEVVTPTWVLVGGVL **(SEQ. ID. NO.: 18)**
NS3/4A-RPT-pVAX	TKYMTCMSADLEVVRPTWVLVGGVL **(SEQ. ID. NO.: 19)**
NS3/4A-RPA-pVAX	TKYMTCMSADLEVVRPAWVLVGGVL **(SEQ. ID. NO.: 20)**
NS3/4A-CST-pVAX	TKYMTCMSADLEVVCSTWVLVGGVL **(SEQ. ID. NO.: 21)**
NS3/4A-CCST-pVAX	TKYMTCMSADLEVCCSTWVLVGGVL **(SEQ. ID. NO.: 22)**
NS3/4A-SSST-pVAX	TKYMTCMSADLEVSSSTWVLVGGVL **(SEQ. ID. NO.: 23)**
NS3/4A-SSSSCST-pVAX	TKYMTCMSADSSSSCSTWVLVGGVL **(SEQ. ID. NO.: 24)**
NS3A/4A-VVVVTST-pVAX	TKYMTCMSADVVVVTSTWVLVGGVL **(SEQ. ID. NO.: 25)**
NS5-pVAX	ASEDVVCCSMSYTWTG **(SEQ. ID. NO.: 27)**
NS5A/B-pVAX	SSEDVVCCSMWVLVGGVL **(SEQ. ID. NO.: 26)**

*The wild type sequence for the NS3/4A fragment is NS3/4A-pVAX. The NS3/4A breakpoint is identified by underline, wherein the P1 position corresponds to the first Thr (T) and the P1′ position corresponds to the next following amino acid the NS3/4A-pVAX sequence. In the wild type NS3/4A sequence the NS3 protease cleaves between the P1 and P1′ positions.

The nucleic acid embodiments include nucleotides encoding the HCV peptides described herein (**SEQ. ID. NOs.: 2-11**) or fragments thereof at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 14 and 15**). Some embodiments for example, include genomic DNA, RNA, and cDNA encoding these HCV peptides. The HCV nucleotide embodiments not only include the DNA sequences shown in the sequence listing (e.g., **SEQ. ID. NO.: 1**) but also include nucleotide sequences encoding the amino acid sequences shown in the sequence listing (e.g., **SEQ. ID. NOs.: 2-11**) and any nucleotide sequence that hybridizes to the DNA sequences shown in the sequence listing under stringent conditions (e.g., hybridization to filter-bound DNA in 0.5 M $NaHPO_4$, 7.0% sodium dodecyl sulfate (SDS), 1 mM EDTA at 50°C) and washing in 0.2 X SSC/0.2% SDS at 50°C and any nucleotide sequence that hybridizes to the DNA sequences that encode an amino acid sequence provided in the sequence listing (**SEQ. ID. NOs.: 2-11**) under less stringent conditions (e.g., hybridization in 0.5 M $NaHPO_4$, 7.0% sodium dodecyl sulfate (SDS), 1 mM EDTA at 37°C and washing in 0.2X SSC/0.2% SDS at 37°C).

The nucleic acid embodiments of the invention also include fragments, modifications, derivatives, and variants of the sequences described above. Desired embodiments, for example, include nucleic acids having at least 12 consecutive bases of one of the novel HCV sequences or a sequence complementary thereto and preferred fragments include at least 12 consecutive bases of a nucleic acid encoding the NS3/4A molecule of **SEQ. ID. NO.: 2** or a mutant NS3/4A molecule of **SEQ. ID. NOs.: 3-13** or a sequence complementary thereto.

In this regard, the nucleic acid embodiments described herein can have from 12 to approximately 2079 consecutive nucleotides. Some DNA fragments, for example, include nucleic acids having at least 12-15, 15-20, 20-30, 30-50, 50-100, 100-200, 200-500, 500-1000, 1000-1500, or 1500-2079 consecutive nucleotides of **SEQ. ID. NO.: 1** or a complement thereof. These nucleic acid embodiments can also be altered by substitution, addition, or deletion so long as the alteration does not significantly affect the structure or function (e.g., ability to serve as an immunogen) of the HCV nucleic acid. Due to the degeneracy of nucleotide coding sequences, for example, other DNA sequences that encode substantially the same HCV amino acid sequence as depicted in **SEQ. ID. NOs.: 2-13** can be used in some embodiments. These include, but are not limited to, nucleic acid sequences encoding all or portions of HCV peptides (**SEQ. ID. NOs.: 2-13**) or nucleic acids that complement all or part of this sequence that have been altered by the substitution of different codons that encode a functionally equivalent amino acid residue within the sequence, thus producing a silent change, or a functionally non-equivalent amino acid residue within the sequence, thus producing a detectable change. Accordingly, the nucleic acid embodiments of the invention are said to be consisting essentially of nucleic acids encoding any one of **SEQ. ID. NOs.: 2-27** in light of the modifications above.

By using the nucleic acid sequences described above, probes that complement these molecules can be designed and manufactured by oligonucleotide synthesis. Desirable probes comprise a nucleic acid sequence of (**SEQ. ID. NO.: 1**) that is unique to this HCV isolate. These probes can be used to screen cDNA from patients so as to isolate natural sources of HCV, some of which may be novel HCV sequences in themselves. Screening can be by filter hybridization or by PCR, for example. By filter

hybridization, the labeled probe preferably contains at least 15-30 base pairs of the nucleic acid sequence of (**SEQ. ID. NO.: 1**) that is unique to to this NS3/4A peptide. The hybridization washing conditions used are preferably of a medium to high stringency. The hybridization can be performed in 0.5M $NaHPO_4$, 7.0% sodium dodecyl sulfate (SDS), 1 mM EDTA at 42°C overnight and washing can be performed in 0.2X SSC/0.2% SDS at 42°C. For guidance regarding such conditions see, for example, Sambrook et al., 1989, Molecular Cloning, A Laboratory Manual, Cold Springs Harbor Press, N.Y.; and Ausubel et al., 1989, Current Protocols in Molecular Biology, Green Publishing Associates and Wiley Interscience, N.Y. both of which are herein expressly incorporated by reference.

HCV nucleic acids can also be isolated from patients infected with HCV using the nucleic acids described herein. (See also *Example 1)*. Accordingly, RNA obtained from a patient infected with HCV is reverse transcribed and the resultant cDNA is amplified using PCR or another amplification technique. The primers are preferably obtained from the NS3/4A sequence (**SEQ. ID. NO.: 1**).

For a review of PCR technology, see Molecular Cloning to Genetic Engineering White, B.A. Ed. in Methods in Molecular Biology 67: Humana Press, Totowa (1997), the disclosure of which is incorporated herein by reference in its entirety and the publication entitled "PCR Methods and Applications" (1991, Cold Spring Harbor Laboratory Press), the disclosure of which is incorporated herein by reference in its entirety. For amplification of mRNAs, it is within the scope of the invention to reverse transcribe mRNA into cDNA followed by PCR (RT-PCR); or, to use a single enzyme for both steps as described in U.S. Patent No. 5,322,770, the disclosure of which is incorporated herein by reference in its entirety. Another technique involves the use of Reverse Transcriptase Asymmetric Gap Ligase Chain Reaction (RT-AGLCR), as described by Marshall R.L. et al. (*PCR Methods and Applications* 4:80-84, 1994), the disclosure of which is incorporated herein by reference in its entirety.

Briefly, RNA is isolated, following standard procedures. A reverse transcription reaction is performed on the RNA using an oligonucleotide primer specific for the most 5' end of the amplified fragment as a primer of first strand synthesis. The resulting RNA/DNA hybrid is then "tailed" with guanines using a standard terminal transferase

reaction. The hybrid is then digested with RNAse H, and second strand synthesis is primed with a poly-C primer. Thus, cDNA sequences upstream of the amplified fragment are easily isolated. For a review of cloning strategies which can be used, see e.g., Sambrook et al., 1989, supra.

In each of these amplification procedures, primers on either side of the sequence to be amplified are added to a suitably prepared nucleic acid sample along with dNTPs and a thermostable polymerase, such as Taq polymerase, Pfu polymerase, or Vent polymerase. The nucleic acid in the sample is denatured and the primers are specifically hybridized to complementary nucleic acid sequences in the sample. The hybridized primers are then extended. Thereafter, another cycle of denaturation, hybridization, and extension is initiated. The cycles are repeated multiple times to produce an amplified fragment containing the nucleic acid sequence between the primer sites. PCR has further been described in several patents including US Patents 4,683,195, 4,683,202 and 4,965,188, the disclosures of which are incorporated herein by reference in their entirety.

The primers are selected to be substantially complementary to a portion of the nucleic acid sequence of **(SEQ. ID. NO.: 1)** that is unique to this NS3/4A molecule, thereby allowing the sequences between the primers to be amplified. Preferably, primers are at least 16-20, 20-25, or 25-30 nucleotides in length. The formation of stable hybrids depends on the melting temperature (Tm) of the DNA. The Tm depends on the length of the primer, the ionic strength of the solution and the G+C content. The higher the G+C content of the primer, the higher is the melting temperature because G:C pairs are held by three H bonds whereas A:T pairs have only two. The G+C content of the amplification primers described herein preferably range between 10 and 75 %, more preferably between 35 and 60 %, and most preferably between 40 and 55 %. The appropriate length for primers under a particular set of assay conditions can be empirically determined by one of skill in the art.

The spacing of the primers relates to the length of the segment to be amplified. In the context of the embodiments described herein, amplified segments carrying nucleic acid sequence encoding HCV peptides can range in size from at least about 25 bp to the entire length of the HCV genome. Amplification fragments from 25-1000 bp are typical, fragments from 50-1000 bp are preferred and fragments from 100-600 bp

are highly preferred. It will be appreciated that amplification primers can be of any sequence that allows for specific amplification of the NS3/4A region and can, for example, include modifications such as restriction sites to facilitate cloning.

The PCR product can be subcloned and sequenced to ensure that the amplified sequences represent the sequences of an HCV peptide. The PCR fragment can then be used to isolate a full length cDNA clone by a variety of methods. For example, the amplified fragment can be labeled and used to screen a cDNA library, such as a bacteriophage cDNA library. Alternatively, the labeled fragment can be used to isolate genomic clones via the screening of a genomic library. Additionally, an expression library can be constructed utilizing cDNA synthesized from, for example, RNA isolated from an infected patient. In this manner, HCV geneproducts can be isolated using standard antibody screening techniques in conjunction with antibodies raised against the HCV gene product. (For screening techniques, see, for example, Harlow, E. and Lane, eds., 1988, Antibodies: A Laboratory Manual, Cold Spring Harbor Press, Cold Spring Harbor., herein expressly incorporated by reference in its entirety)

Embodiments of the invention also include (a) DNA vectors that contain any of the foregoing nucleic acid sequence and/or their complements (i.e., antisense); (b) DNA expression vectors that contain any of the foregoing nucleic acid sequences operatively associated with a regulatory element that directs the expression of the nucleic acid; and (c) genetically engineered host cells that contain any of the foregoing nucleic acid sequences operatively associated with a regulatory element that directs the expression of the coding sequences in the host cell. These recombinant constructs are capable of replicating autonomously in a host cell. Alternatively, the recombinant constructs can become integrated into the chromosomal DNA of a host cell. Such recombinant polynucleotides typically comprise an HCV genomic or cDNA polynucleotide of semi-synthetic or synthetic origin by virtue of human manipulation. Therefore, recombinant nucleic acids comprising these sequences and complements thereof that are not naturally occurring are provided.

Although nucleic acids encoding an HCV peptide or nucleic acids having sequences that complement an HCV gene as they appear in nature can be employed, they will often be altered, e.g., by deletion, substitution, or insertion and can be

accompanied by sequence not present in humans. As used herein, regulatory elements include, but are not limited to, inducible and non-inducible promoters, enhancers, operators and other elements known to those skilled in the art that drive and regulate expression. Such regulatory elements include, but are not limited to, the cytomegalovirus hCMV immediate early gene, the early or late promoters of SV40 adenovirus, the lac system, the trp system, the TAC system, the TRC system, the major operator and promoter regions of phage A, the control regions of fd coat protein, the promoter for 3-phosphoglycerate kinase, the promoters of acid phosphatase, and the promoters of the yeast -mating factors.

In addition, recombinant HCV peptide-encoding nucleic acid sequences and their complementary sequences can be engineered so as to modify their processing or expression. For example, and not by way of limitation, the HCV nucleic acids described herein can be combined with a promoter sequence and/or ribosome binding site, or a signal sequence can be inserted upstream of HCV peptide-encoding sequences so as to permit secretion of the peptide and thereby facilitate harvesting or bioavailability. Additionally, a given HCV nucleic acid can be mutated *in vitro* or *in vivo*, to create and/or destroy translation, initiation, and/or termination sequences, or to create variations in coding regions and/or form new restriction sites or destroy preexisting ones, or to facilitate further *in vitro* modification. (*See Example 1*). Any technique for mutagenesis known in the art can be used, including but not limited to, *in vitro* site-directed mutagenesis. (Hutchinson et al., *J. Biol. Chem.*, 253:6551 (1978), herein incorporated by reference in its entirety).

Further, nucleic acids encoding other proteins or domains of other proteins can be joined to nucleic acids encoding an HCV peptide so as to create a fusion protein. Nucleotides encoding fusion proteins can include, but are not limited to, a full length NS3/4A sequence (**SEQ. ID. NO.: 2**), mutant NS3/4A sequences (e.g., **SEQ. ID. NOs.: 3-11**) or a peptide fragment of an NS3/4A sequence fused to an unrelated protein or peptide, such as for example, poly histidine, hemagglutinin, an enzyme, fluorescent protein, or luminescent protein, as discussed below. Surprisingly, it was discovered that the NS3/4A-pVAX was significantly more immunogenic than NS3-pVAX vectors when

injected into an immunocompetent mammal. The example below describes these experiments in greater detail.

EXAMPLE 2

To determine whether a humoral immune response was elicited by the NS3-pVAX and NS3/4A-pVAX vectors, the expression constructs described in *Example 1* were purified using the Qiagen DNA purification system, according to the manufacturer's instructions and the purified DNA vectors were used to immunize groups of four to ten Balb/c mice. The plasmids were injected directly into regenerating tibialis anterior (TA) muscles as previously described (Davis et al., *Human Gene Therapy* 4(6):733 (1993), herein expressly incorporated by reference). In brief, mice were injected intramuscularly with 50 μl/TA of 0.01mM cardiotoxin (Latoxan, Rosans, France) in 0.9% sterile NaCl. Five days later, each TA muscle was injected with 50 μl PBS containing either rNS3 or DNA.

Inbred mouse strains C57/BL6 (H-2b) Balb/C (H-2d), and CBA (H-2k) were obtained from the breeding facility at Möllegard Denmark, Charles River Uppsala, Sweden, or B&K Sollentuna Sweden. All mice were female and were used at 4-8 weeks of age. For monitoring of humoral responses, all mice received a booster injection of 50 μl /TA of plasmid DNA every fourth week. In addition, some mice were given recombinant NS3 (rNS3) protein, which was purified, as described herein. The mice receiving rNS3 were immunized no more than twice. All mice were bled twice a month.

Enzyme immunosorbent assays (EIAs) were used to detect the presence of murine NS3 antibodies. These assays were performed essentially as described (Chen et al., *Hepatology* 28(1): 219 (1998)). Briefly, rNS3 was passively adsorbed overnight at 4°C to 96-well microtiter plates (Nunc, Copenhagen, Denmark) at 1 μg/ml in 50 mM sodium carbonate buffer (pH 9.6). The plates were then blocked by incubation with dilution buffer containing PBS, 2% goat serum, and 1% bovine serum albumin for one hour at 37°C. Serial dilutions of mouse sera starting at 1:60 were then incubated on the plates for one hour. Bound murine serum antibodies were detected by an alkaline phosphatase conjugated goat anti-mouse IgG (Sigma Cell Products, Saint Louis, MO)

followed by addition of the substrate pNPP (1 tablet/5ml of 1M Diethanol amine buffer with 0.5 mM $MgCl_2$). The reaction was stopped by addition of 1M NaOH and absorbency was read at 405 nm.

After four weeks, four out of five mice immunized with NS3/4A-pVAX had developed NS3 antibodies, whereas one out of five immunized with NS3-pVAX had developed antibodies (**FIGURE 1**). After six weeks, four out of five mice immunized with NS3/4A-pVAX had developed high levels ($>10^4$) of NS3 antibodies (mean levels 10800±4830) and one had a titer of 2160. Although all mice immunized with NS3-pVAX developed NS3 antibodies, none of them developed levels as high as that produced by the NS3/4A-pVAX construct (mean levels 1800±805). The antibody levels elicited by the NS3/4A fusion construct were significantly higher than those induced by NS3-pVAX at six weeks (mean ranks 7.6 v.s 3.4, $p<0.05$, Mann-Whitney rank sum test, and $p<0.01$, Students t-test). Thus, immunization with either NS3-pVAX or NS3/4A-pVAX resulted in the production of anti-NS3 antibodies, but the NS3/4A fusion gene was a more potent immunogen. The example below describes experiments that were performed to determine if mutant NS3/4A peptides, which lack a proteolytic clevage site, could elicit a potent immune response.

EXAMPLE 3

To test if the enhanced immunogenicity of NS3/4A could be solely attributed to the presence of NS4A, or if the NS3/4A fusion protein in addition had to be cleaved at the NS3/4A junction, new experiments were performed. In a first experiment, the immunogenicity of the NS3–pVAX, NS3/4A-pVAX, and mutant NS3/4A constructs were compared in Balb/c mice. Mice were immunized on week 0 as described above, and, after two weeks, all mice were bled and the presence of antibodies to NS3 at a serum dilution of 1:60 was determined (**TABLE 2**). Mice were bled again on week 4. As shown in **TABLE 2**, all the constructs induced an immune reponse; the mutant constructs, for example, the NS3/4A-TGT-pVAX vector was comparable to the NS3-pVAX vector (4/10 vs. 0/10; NS, Fisher's exact test). The NS3/4A–pVAX vector, however, continued to be the most potent immunogen. Thus, all of the HCV constructs that were introduced into mice were capable of eliciting an immune response against

NS3, however, the NS4A sequence and a functional proteolytic cleavage site between the NS3 and NS4A sequences provided for a more potent immune response.

TABLE 2

Weeks from 1st immunization	No. of antibody responders to the respective immunogen after one 100μg *i.m* immunization		
	NS3-pVAX	wild-type NS3/4A-pVAX	mutant example NS3/4A-TGT-pVAX
2	0/10	17/20	4/10
4	0/10 (<60)	20/20 (2415±3715) 55% > 10^3 10% > 10^4	10/10 (390±639) 50% >10^2 10% > 10^3

During the chronic phase of infection, HCV replicates in hepatocytes, and spreads within the liver. A major factor in combating chronic and persistent viral infections is the cell-mediated immune defense system. CD4+ and CD8+ lymphocytes infiltrate the liver during the chronic phase of HCV infection, but they are incapable of clearing the virus or preventing liver damage. In addition, persistent HCV infection is associated with the onset of hepatocellular carcinoma (HCC). The examples below describe experiments that were performed to determine whether the NS3 and NS3/4A construct were capable of eliciting a T-cell mediated immune response against NS3.

EXAMPLE 4

To study whether the constructs described above were capable of eliciting a cell-mediated response against NS3, an *in vivo* tumor growth assay was perfomed. To this end, an SP2/0 tumor cell line stably transfected with the NS3/4A gene was made. The pcDNA3.1 plasmid containing the NS3/4A gene was linearized by BglII digestion. A total of 5μg linearized plasmid DNA was mixed with 60μg transfection reagent

(Superfect, Qiagen, Germany) and the mixture was added to a 50% confluent layer of SP2/0 cells in a 35 mm dish. The transfected SP2/0 cells (NS3/4A-SP2/0) were grown for 14 days in the presence of 800μg/ml geneticin and individual clones were isolated. A stable NS3/4A-expressing SP2/0 clone was identified using PCR and RTPCR. The cloned cell line was maintained in DMEM containing 10% fetal bovine serum, L-glutamine, and penicillin-streptomycin.

The *in vivo* growth kinetics of the SP2/0 and the NS3/4A-SP2/0 cell lines were then evaluated in Balb/c mice. Mice were injected subcutaneously with 2 x 10^6 tumor cells in the right flank. Each day the size of the tumor was determined through the skin. The growth kinetics of the two cell lines was comparable. The mean tumor sizes did not differ between the two cell lines at any time point, for example. (*See* **TABLE 3**). The example below describes experiments that were performed to determine whether mice immunized with the NS3/4A constructs had developed a T-cell response against NS3.

TABLE 3

Mouse ID	Tumor cell line	Maximum *in vivo* tumor size at indicated time point								
		5	6	7	8	11	12	13	14	15
1	SP2/0	1.6	2.5	4.5	6.0	10.0	10.5	11.0	12.0	12.0
2	SP2/0	1.0	1.0	2.0	3.0	7.5	7.5	8.0	11.5	11.5
3	SP2/0	2.0	5.0	7.5	8.0	11.0	11.5	12.0	12.0	13.0
4	SP2/0	4.0	7.0	8.0	10.0	13.0	15.0	16.5	16.5	17.0
5	SP2/0	1.0	1.0	3.0	4.0	5.0	6.0	6.0	6.0	7.0
Group mean		1.92	3.3	5.0	6.2	9.3	10.1	10.7	11.6	12.1
6	NS3/4A-SP2/0	1.0	2.0	3.0	3.5	4.0	5.5	6.0	7.0	8.0
7	NS3/4A-SP2/0	2.0	2.5	3.0	5.0	7.0	9.0	9.5	9.5	11.0
8	NS3/4A-SP2/0	1.0	2.0	3.5	3.5	9.5	11.0	12.0	14.0	14.0

9	NS3/4A-SP2/0	1.0	1.0	2.0	6.0	11.5	13.0	14.5	16.0	18.0
10	NS3/4A-SP2/0	3.5	6.0	7.0	10.5	15.0	15.0	15.0	15.5	20.0
Group mean		1.7	2.7	3.7	5.7	9.4	10.7	11.4	12.4	14.2
p-value of student's t-test comparison between group means		0.7736	0.6918	0.4027	0.7903	0.9670	0.7986	0.7927	0.7508	0.4623

EXAMPLE 5

To examine whether a T-cell response is elicited by the NS3/4A immunization, the capacity of an immunized mouse's immune defense system to attack the NS3-expressing tumor cell line was assayed. The protocol for testing for *in vivo* inhibition of tumor growth of the SP2/0 myeloma cell line in Balb/c mice has been described in detail previously (Encke et al., *J. Immunol.* 161:4917 (1998), herein expressly incorporated by reference in its entirety). Inhibition of tumor growth in this model is dependent on the priming of cytotoxic T lymphocytes (CTLs). Briefly, groups of ten mice were immunized *i.m.* five times with one month intervals with either 100µg NS3-pVAX or 100 µg NS3/4A-pVAX. Two weeks after the last immunization 2 x 10^6 SP2/0 or NS3/4A-SP2/0 cells were injected into the right flank of each mouse. Two weeks later the mice were sacrificed and the maximum tumor sizes were measured. There was no difference between the mean SP2/0 and NS3/4A-SP2/0 tumor sizes in the NS3-pVAX immunized mice (*See* **TABLE 4**).

TABLE 4

Mouse ID	Immunogen	Dose (µg)	Tumor cell line	Tumor growth	Maximum tumor size (mm)
1	NS3-pVAX	100	SP2/0	Yes	5
2	NS3-pVAX	100	SP2/0	Yes	15
3	NS3-pVAX	100	SP2/0	No	-
4	NS3-pVAX	100	SP2/0	Yes	6
5	NS3-pVAX	100	SP2/0	Yes	13
Group total				4/5	9.75±4.992

6	NS3-pVAX	100	NS3/4A-SP2/0	Yes	9
7	NS3-pVAX	100	NS3/4A-SP2/0	Yes	8
8	NS3-pVAX	100	NS3/4A-SP2/0	Yes	7
9	NS3-pVAX	100	NS3/4A-SP2/0	No	-
10	NS3-pVAX	100	NS3/4A-SP2/0	No	-
				3/5	8.00±1.00

Note: Statistical analysis (StatView): Student's t-test on maximum tumor size. P-values < 0.05 are considered significant.

Unpaired t-test for Max diam
Grouping Variable: Column 1
Hypothesized Difference = 0
Row exclusion: NS3DNA-Tumor-001213

	Mean Diff.	DF	t-Value	P-Value
NS3-sp2, NS3-spNS3	1.750	5	0.58	0.584

Group Info for Max diam
Grouping Variable: Column 1
Row exclusion: NS3DNA-Tumor-001213

	Count	Mean	Variance	Std. Dev.	Std. Err
NS3-sp2	4	9.750	24.917	4.992	2.496
NS3-spNS3	3	8.000	1.000	1.000	0.57

In the next set of experiments, the inhibition of SP2/0 or NS3/4A-SP2/0 tumor growth was evaluated in NS3/4A-pVAX immunized Balb/c mice. In mice immunized with the NS3/4A-pVAX plasmid the growth of NS3/4A-SP2/0 tumor cells was significantly inhibited as compared to growth of the non-transfected SP2/0 cells. (*See* **TABLE 5**). Thus, NS3/4A-pVAX immunization elicits CTLs that inhibit growth of cells expressing NS3/4A *in vivo*. The example below describes experiments that were performed to analyze the efficiency of various NS3 containing compositions in eliciting a cell-mediated response to NS3.

TABLE 5

Mouse ID	Immunogen	Dose (μg)	Tumor cell line	Tumor growth	Maximum tumor size (mm)
11	NS3/4A-pVAX	100	SP2/0	No	-
12	NS3/4A-pVAX	100	SP2/0	Yes	24
13	NS3/4A-pVAX	100	SP2/0	Yes	9
14	NS3/4A-pVAX	100	SP2/0	Yes	11
15	NS3/4A-pVAX	100	SP2/0	Yes	25
				4/5	17.25±8.421
16	NS3/4A-pVAX	100	NS3/4A-SP2/0	No	-
17	NS3/4A-pVAX	100	NS3/4A-SP2/0	Yes	9
18	NS3/4A-pVAX	100	NS3/4A-SP2/0	Yes	7
19	NS3/4A-pVAX	100	NS3/4A-SP2/0	Yes	5
20	NS3/4A-pVAX	100	NS3/4A-SP2/0	Yes	4
				4/5	6.25±2.217

Note: Statistical analysis (StatView): Student's t-test on maximum tumor size. P-values < 0.05 are considered significant.

Unpaired t-test for Max diam
Grouping Variable: Column 1
Hypothesized Difference = 0
Row exclusion: NS3DNA-Tumor-001213

	Mean Diff.	DF	t-Value	P-Value
NS3/4-sp2, NS3/4-spNS3	11.000	6	2.526	0.044

Group Info for Max diam
Grouping Variable: Column 1
Row exclusion: NS3DNA-Tumor-001213

	Count	Mean	Variance	Std. Dev.	Std. Err
NS3/4-sp2	4	17.250	70.917	8.421	4.211
NS3/4-spNS3	4	6.250	4.917	2.217	1.109

EXAMPLE 6

To analyze whether administration of different NS3 containing compositions affected the elicitation of a cell-mediated immune response, mice were immunized with PBS, rNS3, irrelevant DNA or the NS3/4A construct, and tumor sizes were determined, as described above. Only the NS3/4A construct was able to elicit a T-cell response sufficient to cause a statistically significant reduction in tumor size (*See* **TABLE 6**).

The example below describes experiments that were performed to determine whether the reduction in tumor size can be attributed to the generation of NS3-specific T-lymphocytes.

TABLE 6

Mouse ID	Immunogen	Dose (µg)	Tumor cell line	Anti-NS3	Tumor growth	Maximum tumor size (mm)
1	NS3-pVAX	10	NS3/4A-SP2/0	<60	+	12.0
2	NS3-pVAX	10	NS3/4A-SP2/0	<60	+	20.0
3	NS3-pVAX	10	NS3/4A-SP2/0	60	+	18.0
4	NS3-pVAX	10	NS3/4A-SP2/0	<60	+	13.0
5	NS3-pVAX	10	NS3/4A-SP2/0	<60	+	17.0
Group mean				60	5/5	16.0±3.391
6	NS3-pVAX	100	NS3/4A-SP2/0	2160	+	10.0
7	NS3-pVAX	100	NS3/4A-SP2/0	<60	-	-
8	NS3-pVAX	100	NS3/4A-SP2/0	<60	-	-
9	NS3-pVAX	100	NS3/4A-SP2/0	360	-	-
10	NS3-pVAX	100	NS3/4A-SP2/0	<60	+	12.5
Group mean				1260	2/5	11.25±1.768
11	NS3/4A-pVAX	10	NS3/4A-SP2/0	<60	+	10.0
12	NS3/4A-pVAX	10	NS3/4A-SP2/0	<60	-	-
13	NS3/4A-pVAX	10	NS3/4A-SP2/0	<60	-	-
14	NS3/4A-pVAX	10	NS3/4A-SP2/0	<60	+	13.0
15	NS3/4A-pVAX	10	NS3/4A-SP2/0	<60	+	13.5
Group mean				<60	3/5	12.167±1.893
16	NS3/4A-pVAX	100	NS3/4A-SP2/0	60	+	10.0
17	NS3/4A-pVAX	100	NS3/4A-SP2/0	360	-	-
18	NS3/4A-pVAX	100	NS3/4A-SP2/0	2160	+	8.0
19	NS3/4A-pVAX	100	NS3/4A-SP2/0	2160	+	12.0
20	NS3/4A-pVAX	100	NS3/4A-SP2/0	2160	+	7.0
Group mean				1380	4/5	9.25±2.217
36	p17-pcDNA3	100	NS3/4A-SP2/0	<60	+	20.0
37	p17-pcDNA3	100	NS3/4A-SP2/0	<60	+	7.0
38	p17-pcDNA3	100	NS3/4A-SP2/0	<60	+	11.0
39	p17-pcDNA3	100	NS3/4A-SP2/0	<60	+	15.0
40	p17-pcDNA3	100	NS3/4A-SP2/0	<60	+	18.0
Group mean				<60	5/5	14.20±5.263
41	rNS3/CFA	20	NS3/4A-SP2/0	>466560	+	13.0
42	rNS3/CFA	20	NS3/4A-SP2/0	>466560	-	-
43	rNS3/CFA	20	NS3/4A-SP2/0	>466560	+	3.5
44	rNS3/CFA	20	NS3/4A-SP2/0	>466560	+	22.0
45	rNS3/CFA	20	NS3/4A-SP2/0	>466560	+	17.0

Group mean				466560	4/5	17.333±4.509
46	PBS	-	NS3/4A-SP2/0	<60	+	10.0
47	PBS	-	NS3/4A-SP2/0	<60	+	16.5
48	PBS	-	NS3/4A-SP2/0	60	+	15.0
49	PBS	-	NS3/4A-SP2/0	<60	+	21.0
50	PBS	-	NS3/4A-SP2/0	<60	+	15.0
51	PBS	-	NS3/4A-SP2/0	<60	-	-
Group mean				60	5/6	15.50±3.937

Note: Statistical analysis (StatView): Student's t-test on maximum tumor size. P-values < 0.05 are considered as significant.

Unpaired t-test for Largest Tumor size
Grouping Variable: group
Hypothesized Difference = 0

	Mean Diff.	DF	t-Value	P-Value
p17-sp3-4, NS3-100-sp3-4	2.950	5	.739	.4933
p17-sp3-4, NS3/4-10-sp3-4	2.033	6	.628	.5532
p17-sp3-4, NS3-10-sp3-4	-1.800	8	-.643	.5383
p17-sp3-4, NS3/4-100-sp3-4	4.950	7	1.742	.1250
p17-sp3-4, PBS-sp3-4	-1.300	8	-.442	.6700
p17-sp3-4, rNS3-sp3-4	-3.133	6	-.854	.4259
NS3-100-sp3-4, NS3/4-10-sp3-4	-.917	3	-.542	.6254
NS3-100-sp3-4, NS3-10-sp3-4	-4.750	5	-1.811	.1299
NS3-100-sp3-4, NS3/4-100-sp3-4	2.000	4	1.092	.3360
NS3-100-sp3-4, PBS-sp3-4	-4.250	5	-1.408	.2183
NS3-100-sp3-4, rNS3-sp3-4	-6.083	3	-1.744	.1795
NS3/4-10-sp3-4, NS3-10-sp3-4	-3.833	6	-1.763	.1283
NS3/4-10-sp3-4, NS3/4-100-sp3-4	2.917	5	1.824	.1277
NS3/4-10-sp3-4, PBS-sp3-4	-3.333	6	-1.344	.2274
NS3/4-10-sp3-4, rNS3-sp3-4	-5.167	4	-1.830	.1412
NS3-10-sp3-4, NS3/4-100-sp3-4	6.750	7	3.416	.0112
NS3-10-sp3-4, PBS-sp3-4	.500	8	.215	.8350
NS3-10-sp3-4, rNS3-sp3-4	-1.333	6	-.480	.6480
NS3/4-100-sp3-4, PBS-sp3-4	-6.250	7	-2.814	.0260
NS3/4-100-sp3-4, rNS3-sp3-4	-8.083	5	-3.179	.0246
PBS-sp3-4, rNS3-sp3-4	-1.833	6	-.607	.5662

EXAMPLE 7

To determine whether NS3-specific T-cells were elicited by the NS3/4A immunizations, an *in vitro* T-cell mediated tumor cell lysis assay was employed. The assay has been described in detail previously (Sallberg et al., *J. Virol.* 71:5295 (1997),

herein expressly incorporated by reference in its entirety). Briefly, groups of five Balb/c mice were immunized three times with 100μg NS3/4A-pVAX *i.m.* Two weeks after the last injection the mice were sacrificed and splenocytes were harvested. Re-stimulation cultures with 3 x 10^6 splenocytes and 3 x 10^6 NS3/4A-SP2/0 cells were set. After five days, a standard Cr^{51}-release assay was performed using NS3/4A-SP2/0 or SP2/0 cells as targets. Percent specific lysis was calculated as the ratio between lysis of NS3/4A-SP2/0 cells and lysis of SP2/0 cells. Only mice immunized with NS3/4A-pVAX displayed specific lysis over 10% in four out of five tested mice, using an effector to target ratio of 20:1 (*See* **FIGURES 2A** and **2B**). The section below describes several of the embodied HCV polypeptides in greater detail.

The nucleic acids encoding the HCV peptides, described above, can be manipulated using conventional techniques in molecular biology so as to create recombinant constructs that express the HCV peptides. The embodied HCV peptides or derivatives thereof, include but are not limited to, those containing as a primary amino acid sequence all of the amino acid sequence substantially as depicted in the Sequence Listing (**SEQ. ID. NOs.: 2-11**) and fragments of **SEQ. ID. NOs.: 2-11** at least four amino acids in length (e.g., **SEQ. ID. NOs.: 14-16**) including altered sequences in which functionally equivalent amino acid residues are substituted for residues within the sequence resulting in a silent change. Preferred fragments of a sequence of **SEQ. ID. NOs.: 2-11** are at least four amino acids and comprise amino acid sequence unique to the discovered NS3/4A peptide or mutants thereof including altered sequences in which functionally equivalent amino acid residues are substituted for residues within the sequence resulting in a silent change. The HCV peptides can be, for example, at least (12-704 amino acids in length (e.g., 12-15, 15-20, 20-25, 25-50, 50-100, 100-150, 150-250, 250-500 or 500-704 amino acids in length).

Embodiments also include HCV peptides that are substantially identical to those described above. That is, HCV peptides that have one or more amino acid residues within **SEQ. ID. NOs.: 2-11** and fragments thereof that are substituted by another amino acid of a similar polarity that acts as a functional equivalent, resulting in a silent alteration. Further, the HCV peptides can have one or more amino acid residues fused to **SEQ. ID. NOs.: 2-11** or a fragment thereof so long as the fusion does not

significantly alter the structure or function (e.g., immunogenic properties) of the HCV peptide. Substitutes for an amino acid within the sequence can be selected from other members of the class to which the amino acid belongs. For example, the non-polar (hydrophobic) amino acids include alanine, leucine, isoleucine, valine, proline, phenylalanine, tryptophan, and methionine. The polar neutral amino acids include glycine, serine, threonine, cysteine, tyrosine, asparagine and glutamine. The positively charged (basic) amino acids include arginine, lysine, and histidine. The negatively charged (acidic) amino acids include aspartic acid and glutamic acid. The aromatic amino acids include phenylalanine, tryptophan, and tyrosine. Accordingly, the peptide embodiments of the invention are said to be consisting essentially of **SEQ. ID. NOs.: 2-27** in light of the modifications described above.

The HCV peptides described herein can be prepared by chemical synthesis methods (such as solid phase peptide synthesis) using techniques known in the art such as those set forth by Merrifield et al., *J. Am. Chem. Soc.* 85:2149 (1964), Houghten et al., *Proc. Natl. Acad. Sci. USA*, 82:51:32 (1985), Stewart and Young (Solid phase peptide synthesis, Pierce Chem Co., Rockford, IL (1984), and Creighton, 1983, Proteins: Structures and Molecular Principles, W. H. Freeman & Co., N.Y., all of which are herein expressly incorporated by reference. Such polypeptides can be synthesized with or without a methionine on the amino terminus. Chemically synthesized HCV peptides can be oxidized using methods set forth in these references to form disulfide bridges.

While the HCV peptides described herein can be chemically synthesized, it can be more effective to produce these polypeptides by recombinant DNA technology. Such methods can be used to construct expression vectors containing the HCV nucleotide sequences described above, for example, and appropriate transcriptional and translational control signals. These methods include, for example, *in vitro* recombinant DNA techniques, synthetic techniques, and *in vivo* genetic recombination. Alternatively, RNA capable of encoding an HCV nucleotide sequence can be chemically synthesized using, for example, synthesizers. See, for example, the techniques described in Oligonucleotide Synthesis, 1984, Gait, M. J. ed., IRL Press, Oxford, which is incorporated by reference herein in its entirety. Accordingly, several

embodiments concern cell lines that have been engineered to express the embodied HCV peptides. For example, some cells are made to express the HCV peptides of **SEQ. ID. NOs.: 2-11** or fragments of these molecules (e.g., **SEQ. ID. NOs.: 14-26**).

A variety of host-expression vector systems can be utilized to express the embodied HCV peptides. Suitable expression systems include, but are not limited to, microorganisms such as bacteria (e.g., *E. coli* or *B. subtilis*) transformed with recombinant bacteriophage DNA, plasmid DNA or cosmid DNA expression vectors containing HCV nucleotide sequences; yeast (e.g., *Saccharomyces*, *Pichia*) transformed with recombinant yeast expression vectors containing the HCV nucleotide sequences; insect cell systems infected with recombinant virus expression vectors (e.g., baculovirus) containing the HCV sequences; plant cell systems infected with recombinant virus expression vectors (e.g., cauliflower mosaic virus, CaMV; tobacco mosaic virus, TMV) or transformed with recombinant plasmid expression vectors (e.g., Ti plasmid) containing HCV sequences; or mammalian cell systems (e.g., COS, CHO, BHK, 293, 3T3) harboring recombinant expression constructs containing promoters derived from the genome of mammalian cells (e.g., metallothionein promoter) or from mammalian viruses (e.g., the adenovirus late promoter; the vaccinia virus 7.5K promoter).

In bacterial systems, a number of expression vectors can be advantageously selected depending upon the use intended for the HCV gene product being expressed. For example, when a large quantity of such a protein is to be produced, for the generation of pharmaceutical compositions of HCV peptide or for raising antibodies to the HCV peptide, for example, vectors which direct the expression of high levels of fusion protein products that are readily purified can be desirable. Such vectors include, but are not limited, to the *E. coli* expression vector pUR278 (Ruther et al., *EMBO* J., 2:1791 (1983), in which the HCV coding sequence can be ligated individually into the vector in frame with the lacZ coding region so that a fusion protein is produced; pIN vectors (Inouye & Inouye, *Nucleic Acids Res.*, 13:3101-3109 (1985); Van Heeke & Schuster, *J. Biol. Chem.*, 264:5503-5509 (1989)); and the like. pGEX vectors can also be used to express foreign polypeptides as fusion proteins with glutathione S-transferase (GST). In general, such fusion proteins are soluble and can be purified from lysed cells

by adsorption to glutathione-agarose beads followed by elution in the presence of free glutathione. The PGEX vectors are designed to include thrombin or factor Xa protease cleavage sites so that the cloned target gene product can be released from the GST moiety.

In an insect system, *Autographa californica* nuclear polyhedrosis virus (AcNPV) is used as a vector to express foreign genes. The virus grows in *Spodoptera frugiperda* cells. The HCV coding sequence can be cloned individually into non-essential regions (for example the polyhedrin gene) of the virus and placed under control of an AcNPV promoter (for example the polyhedrin promoter). Successful insertion of an HCV gene coding sequence will result in inactivation of the polyhedrin gene and production of non-occluded recombinant virus, (i.e., virus lacking the proteinaceous coat coded for by the polyhedrin gene). These recombinant viruses are then used to infect *Spodoptera frugiperda* cells in which the inserted gene is expressed. (See e.g., Smith et al., *J. Virol.* 46: 584 (1983); and Smith, U.S. Pat. No. 4,215,051, herein expressly incorporated by reference in its entirety).

In mammalian host cells, a number of viral-based expression systems can be utilized. In cases where an adenovirus is used as an expression vector, the HCV nucleotide sequence of interest can be ligated to an adenovirus transcription/translation control complex, e.g., the late promoter and tripartite leader sequence. This chimeric gene can then be inserted in the adenovirus genome by *in vitro* or *in vivo* recombination. Insertion in a non-essential region of the viral genome (e.g., region E1 or E3) will result in a recombinant virus that is viable and capable of expressing the HCV gene product in infected hosts. (See e.g., Logan & Shenk, *Proc. Natl. Acad. Sci. USA* 81:3655-3659 (1984)). Specific initiation signals can also be required for efficient translation of inserted HCV nucleotide sequences. These signals include the ATG initiation codon and adjacent sequences.

However, in cases where only a portion of the HCV coding sequence is inserted, exogenous translational control signals, including, perhaps, the ATG initiation codon, can be provided. Furthermore, the initiation codon can be in phase with the reading frame of the desired coding sequence to ensure translation of the entire insert. These exogenous translational control signals and initiation codons can be of a variety of

origins, both natural and synthetic. The efficiency of expression can be enhanced by the inclusion of appropriate transcription enhancer elements, transcription terminators, etc. (See Bittner et al., *Methods in Enzymol.,* 153:516-544 (1987)).

In addition, a host cell strain can be chosen which modulates the expression of the inserted sequences, or modifies and processes the gene product in the specific fashion desired. Such modifications (e.g., glycosylation) and processing (e.g., cleavage) of protein products are important for the function of the protein. Different host cells have characteristic and specific mechanisms for the post-translational processing and modification of proteins and gene products. Appropriate cell lines or host systems can be chosen to ensure the correct modification and processing of the foreign protein expressed. To this end, eukaryotic host cells that possess the cellular machinery for proper processing of the primary transcript, glycosylation, and phosphorylation of the gene product can be used. Such mammalian host cells include, but are not limited to, CHO, VERO, BHK, HeLa, COS, MDCK, 293, 3T3, and WI38.

For long-term, high-yield production of recombinant proteins, stable expression is preferred. For example, cell lines that stably express the HCV peptides described above can be engineered. Rather than using expression vectors that contain viral origins of replication, host cells can be transformed with DNA controlled by appropriate expression control elements (e.g., promoter, enhancer sequences, transcription terminators, polyadenylation sites, etc.), and a selectable marker. Following the introduction of the foreign DNA, engineered cells are allowed to grow for 1-2 days in an enriched media, and then are switched to a selective media. The selectable marker in the recombinant plasmid confers resistance to the selection and allows cells to stably integrate the plasmid into their chromosomes and grow to form foci which in turn are cloned and expanded into cell lines. This method is advantageously used to engineer cell lines which express the HCV gene product.

A number of selection systems can be used, including but not limited to the herpes simplex virus thymidine kinase (Wigler, et al., *Cell* 11:223 (1977), hypoxanthine-guanine phosphoribosyltransferase (Szybalska & Szybalski, *Proc. Natl. Acad. Sci. USA* 48:2026 (1962), and adenine phosphoribosyltransferase (Lowy, et al., *Cell* 22:817 (1980) genes can be employed in tk^-, $hgprt^-$ or $aprt^-$ cells, respectively.

Also, antimetabolite resistance can be used as the basis of selection for the following genes: dhfr, which confers resistance to methotrexate (Wigler, et al., *Proc. Natl. Acad. Sci. USA* 77:3567 (1980); O'Hare, et al., *Proc. Natl. Acad. Sci. USA* 78:1527 (1981); gpt, which confers resistance to mycophenolic acid (Mulligan & Berg, *Proc. Natl. Acad. Sci. USA* 78:2072 (1981); neo, which confers resistance to the aminoglycoside G-418 (Colberre-Garapin, et al., *J. Mol. Biol.* 150:1 (1981); and hygro, which confers resistance to hygromycin (Santerre, et al., *Gene* 30:147 (1984)).

Alternatively, any fusion protein can be readily purified by utilizing an antibody specific for the fusion protein being expressed. For example, a system described by Janknecht et al. allows for the ready purification of non-denatured fusion proteins expressed in human cell lines. (Janknecht, et al., *Proc. Natl. Acad. Sci. USA* 88: 8972-8976 (1991)). In this system, the gene of interest is subcloned into a vaccinia recombination plasmid such that the gene's open reading frame is translationally fused to an amino-terminal tag consisting of six histidine residues. Extracts from cells infected with recombinant vaccinia virus are loaded onto Ni^{2+}nitriloacetic acid-agarose columns and histidine-tagged proteins are selectively eluted with imidazole-containing buffers. The example below describes a method that was used to express the HCV peptides encoded by the embodied nucleic acids.

EXAMPLE 8

To characterize the NS3/4A fusion protein, and the truncated and mutated versions thereof, the vector constructs, described in *Example 1*, were transcribed and translated *in vitro*, and the resulting polypeptides were visualized by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). *In vitro* transcription and translation were performed using the T7 coupled reticulocyte lysate system (Promega, Madison, WI) according to the manufacturer's instructions. All *in vitro* translation reactions of the expression constructs were carried out at 30°C with ^{35}S-labeled methionine (Amersham International, Plc, Buckinghamshire, UK). The labeled proteins were separated on 12% SDS-PAGE gels and visualized by exposure to X-ray film (Hyper Film-MP, Amersham) for 6-18 hours.

The *in vitro* analysis revealed that all proteins were expressed to high amounts from their respective expression constructs. The rNS3 construct (NS3-pVAX vector) produced a single peptide of approximately 61kDa, whereas, the mutant constructs (e.g., the TGT construct (NS3/4A-TGT-pVAX) and the RGT construct (NS3/4A-RGT-pVAX)) produced a single polypeptide of approximately 67 kDa, which is identical to the molecular weight of the uncleaved NS3/4A peptide produced from the NS3/4A-pVAX construct. The cleaved product produced from the expressed NS3/4A peptide was approximately 61 kDa, which was identical in size to the rNS3 produced from the NS3-pVAX vector. These results demonstrated that the expression constructs were functional, the NS3/4A construct was enzymatically active, the rNS3 produced a peptide of the predicted size, and the breakpoint mutations completely abolished cleavage at the NS3–NS4A junction.

The sequences, constructs, vectors, clones, and other materials comprising the embodied HCV nucleic acids and peptides can be in enriched or isolated form. As used herein, "enriched" means that the concentration of the material is many times its natural concentration, for example, at least about 2, 5, 10, 100, or 1000 times its natural concentration, advantageously 0.01%, by weight, preferably at least about 0.1% by weight. Enriched preparations from about 0.5% or more, for example, 1%, 5%, 10%, and 20% by weight are also contemplated. The term "isolated" requires that the material be removed from its original environment (e.g., the natural environment if it is naturally occurring). For example, a naturally-occurring polynucleotide present in a living animal is not isolated, but the same polynucleotide, separated from some or all of the coexisting materials in the natural system, is isolated. It is also advantageous that the sequences be in purified form. The term "purified" does not require absolute purity; rather, it is intended as a relative definition. Isolated proteins have been conventionally purified to electrophoretic homogeneity by Coomassie staining, for example. Purification of starting material or natural material to at least one order of magnitude, preferably two or three orders, and more preferably four or five orders of magnitude is expressly contemplated.

The HCV gene products described herein can also be expressed in plants, insects, and animals so as to create a transgenic organism. Desirable transgenic plant

systems having an HCV peptide include *Arabadopsis*, maize, and *Chlamydomonas*. Desirable insect systems having an HCV peptide include, but are not limited to, *D. melanogaster* and *C. elegans*. Animals of any species, including, but not limited to, amphibians, reptiles, birds, mice, hamsters, rats, rabbits, guinea pigs, pigs, micro-pigs, goats, dogs, cats, and non-human primates, e.g., baboons, monkeys, and chimpanzees can be used to generate transgenic animals having an embodied HCV molecule. These transgenic organisms desirably exhibit germline transfer of HCV peptides described herein.

Any technique known in the art is preferably used to introduce the HCV transgene into animals to produce the founder lines of transgenic animals or to knock out or replace existing HCV genes. Such techniques include, but are not limited to pronuclear microinjection (Hoppe, P. C. and Wagner, T. E., 1989, U.S. Pat. No. 4,873,191); retrovirus mediated gene transfer into germ lines (Van der Putten et al., *Proc. Natl. Acad. Sci., USA* 82:6148-6152 (1985); gene targeting in embryonic stem cells (Thompson et al., *Cell* 56:313-321 (1989); electroporation of embryos (Lo, *Mol Cell. Biol.* 3:1803-1814 (1983); and sperm-mediated gene transfer (Lavitrano et al., *Cell* 57:717-723 (1989); see also Gordon, *Transgenic Animals, Intl. Rev. Cytol.* 115:171-229 (1989), all references are hereby incorporated by reference herein in their entirety.

Following synthesis or expression and isolation or purification of the HCV peptides, the isolated or purified peptide can be used to generate antibodies. Depending on the context, the term "antibodies" can encompass polyclonal, monoclonal, chimeric, single chain, Fab fragments and fragments produced by a Fab expression library. Antibodies that recognize the HCV peptides have many uses including, but not limited to, biotechnological applications, therapeutic/prophylactic applications, and diagnostic applications.

For the production of antibodies, various hosts including goats, rabbits, rats, mice, and humans etc. can be immunized by injection with an HCV peptide. Depending on the host species, various adjuvants can be used to increase immunological response. Such adjuvants include, but are not limited to, ribavirin, Freund's, mineral gels such as aluminum hydroxide, and surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil emulsions, keyhole limpet hemocyanin, and

dinitrophenol. BCG (*Bacillus* Calmette-Guerin) and *Corynebacterium parvum* are also potentially useful adjuvants.

Peptides used to induce specific antibodies can have an amino acid sequence consisting of at least four amino acids, and preferably at least 10 to 15 amino acids. By one approach, short stretches of amino acids encoding fragments of NS3/4A are fused with those of another protein such as keyhole limpet hemocyanin such that an antibody is produced against the chimeric molecule. Additionally, a composition comprising ribavirin and an HCV peptide (**SEQ. ID. NOs.: 2-11**), a fragment thereof at least 3-20 amino acids in length (e.g., 3, 4, 6, 8, 10, 12, 15 or 20 amino acids in length) (e.g., **SEQ. ID. NOs.: 4-26**), or a nucleic acid encoding one or more of these molecules is administered to an animal. While antibodies capable of specifically recognizing HCV can be generated by injecting synthetic 3-mer, 10-mer, and 15-mer peptides that correspond to an HCV peptide into mice, a more diverse set of antibodies can be generated by using recombinant HCV peptides, prepared as decribed above.

To generate antibodies to an HCV peptide, substantially pure peptide is isolated from a transfected or transformed cell. The concentration of the peptide in the final preparation is adjusted, for example, by concentration on an Amicon filter device, to the level of a few micrograms/ml. Monoclonal or polyclonal antibody to the peptide of interest can then be prepared as follows:

Monoclonal antibodies to an HCV peptide can be prepared using any technique that provides for the production of antibody molecules by continuous cell lines in culture. These include, but are not limited to, the hybridoma technique originally described by Koehler and Milstein (*Nature* 256:495-497 (1975), the human B-cell hybridoma technique (Kosbor et al. *Immunol Today* 4:72 (1983); Cote et al *Proc Natl Acad Sci* 80:2026-2030 (1983), and the EBV-hybridoma technique Cole et al. Monoclonal Antibodies and Cancer Therapy, Alan R. Liss Inc, New York N.Y., pp 77-96 (1985). In addition, techniques developed for the production of "chimeric antibodies", the splicing of mouse antibody genes to human antibody genes to obtain a molecule with appropriate antigen specificity and biological activity can be used. (Morrison et al. *Proc Natl Acad Sci* 81:6851-6855 (1984); Neuberger et al. *Nature* 312:604-608(1984); Takeda et al. *Nature* 314:452-454(1985). Alternatively, techniques

described for the production of single chain antibodies (U.S. Pat. No. 4,946,778) can be adapted to produce HCV-specific single chain antibodies. Antibodies can also be produced by inducing *in vivo* production in the lymphocyte population or by screening recombinant immunoglobulin libraries or panels of highly specific binding reagents as disclosed in Orlandi et al., *Proc Natl Acad Sci* 86: 3833-3837 (1989), and Winter G. and Milstein C; *Nature* 349:293-299 (1991).

Antibody fragments that contain specific binding sites for an HCV peptide can also be generated. For example, such fragments include, but are not limited to, the $F(ab')_2$ fragments that can be produced by pepsin digestion of the antibody molecule and the Fab fragments that can be generated by reducing the disulfide bridges of the $F(ab')_2$ fragments. Alternatively, Fab expression libraries can be constructed to allow rapid and easy identification of monoclonal Fab fragments with the desired specificity. (Huse W. D. et al. *Science* 256:1275-1281 (1989)).

By one approach, monoclonal antibodies to an HCV peptide are made as follows. Briefly, a mouse is repetitively inoculated with a few micrograms of the selected protein or peptides derived therefrom over a period of a few weeks. The mouse is then sacrificed, and the antibody producing cells of the spleen isolated. The spleen cells are fused in the presence of polyethylene glycol with mouse myeloma cells, and the excess unfused cells destroyed by growth of the system on selective media comprising aminopterin (HAT media). The successfully fused cells are diluted and aliquots of the dilution placed in wells of a microtiter plate where growth of the culture is continued. Antibody-producing clones are identified by detection of antibody in the supernatant fluid of the wells by immunoassay procedures, such as ELISA, as originally described by Engvall, E., *Meth. Enzymol.* 70:419 (1980), and derivative methods thereof. Selected positive clones can be expanded and their monoclonal antibody product harvested for use. Detailed procedures for monoclonal antibody production are described in Davis, L. et al. Basic Methods in Molecular Biology Elsevier, New York. Section 21-2.

Polyclonal antiserum containing antibodies to heterogenous epitopes of a single protein can be prepared by immunizing suitable animals with the expressed protein or peptides derived therefrom described above, which can be unmodified or modified to enhance immunogenicity. Effective polyclonal antibody production is affected by many

factors related both to the antigen and the host species. For example, small molecules tend to be less immunogenic than others and can require the use of carriers and adjuvant. Also, host animals vary in response to site of inoculations and dose, with both inadequate or excessive doses of antigen resulting in low titer antisera. Small doses (ng level) of antigen administered at multiple intradermal sites appears to be most reliable. An effective immunization protocol for rabbits can be found in Vaitukaitis, J. et al. *J. Clin. Endocrinol. Metab.* 33:988-991 (1971).

Booster injections are given at regular intervals, and antiserum harvested when antibody titer thereof, as determined semi-quantitatively, for example, by double immunodiffusion in agar against known concentrations of the antigen, begins to fall. See, for example, Ouchterlony, O. et al., Chap. 19 in: Handbook of Experimental Immunology D. Wier (ed) Blackwell (1973). Plateau concentration of antibody is usually in the range of 0.1 to 0.2 mg/ml of serum (about 12μM). Affinity of the antisera for the antigen is determined by preparing competitive binding curves, as described, for example, by Fisher, D., Chap. 42 in: Manual of Clinical Immunology, 2d Ed. (Rose and Friedman, Eds.) Amer. Soc. For Microbiol., Washington, D.C. (1980). Antibody preparations prepared according to either protocol are useful in quantitative immunoassays that determine concentrations of antigen-bearing substances in biological samples; they are also used semi-quantitatively or qualitatively (e.g., in diagnostic embodiments that identify the presence of HCV in biological samples). The next section describes how some of the novel nucleic acids and peptides described above can be used in diagnostics.

Diagnostic embodiments

Generally, the embodied diagnostics are classified according to whether a nucleic acid or protein-based assay is used. Some diagnostic assays detect the presence or absence of an embodied HCV nucleic acid sequence in a sample obtained from a patient, whereas, other assays seek to identify whether an embodied HCV peptide is present in a biological sample obtained from a patient. Additionally, the manufacture of kits that incorporate the reagents and methods described herein that allow for the rapid detection and identification of HCV are also embodied. These diagnostic kits can include, for example, an embodied nucleic acid probe or antibody, which specifically detects HCV.

The detection component of these kits will typically be supplied in combination with one or more of the following reagents. A support capable of absorbing or otherwise binding DNA, RNA, or protein will often be supplied. Available supports include membranes of nitrocellulose, nylon or derivatized nylon that can be characterized by bearing an array of positively charged substituents. One or more restriction enzymes, control reagents, buffers, amplification enzymes, and non-human polynucleotides like calf-thymus or salmon-sperm DNA can be supplied in these kits.

Useful nucleic acid-based diagnostics include, but are not limited to, direct DNA sequencing, Southern Blot analysis, dot blot analysis, nucleic acid amplification, and combinations of these approaches. The starting point for these analysis is isolated or purified nucleic acid from a biological sample obtained from a patient suspected of contracting HCV or a patient at risk of contracting HCV. The nucleic acid is extracted from the sample and can be amplified by RT-PCR and/or DNA amplification using primers that correspond to regions flanking the embodied HCV nucleic acid sequences (e.g., NS3/4A (**SEQ. ID. NO.: 1**)).

In some embodiments, nucleic acid probes that specifically hybridize with HCV sequences are attached to a support in an ordered array, wherein the nucleic acid probes are attached to distinct regions of the support that do not overlap with each other. Preferably, such an ordered array is designed to be "addressable" where the distinct locations of the probe are recorded and can be accessed as part of an assay procedure. These probes are joined to a support in different known locations. The knowledge of the precise location of each nucleic acid probe makes these "addressable" arrays particularly useful in binding assays. The nucleic acids from a preparation of several biological samples are then labeled by conventional approaches (e.g., radioactivity or fluorescence) and the labeled samples are applied to the array under conditions that permit hybridization.

If a nucleic acid in the samples hybridizes to a probe on the array, then a signal will be detected at a position on the support that corresponds to the location of the hybrid. Since the identity of each labeled sample is known and the region of the support on which the labeled sample was applied is known, an identification of the presence of the polymorphic variant can be rapidly determined. These approaches are easily

automated using technology known to those of skill in the art of high throughput diagnostic or detection analysis.

Additionally, an approach opposite to that presented above can be employed. Nucleic acids present in biological samples can be disposed on a support so as to create an addressable array. Preferably, the samples are disposed on the support at known positions that do not overlap. The presence of HCV nucleic acids in each sample is determined by applying labeled nucleic acid probes that complement nucleic acids, which encode HCV peptides, at locations on the array that correspond to the positions at which the biological samples were disposed. Because the identity of the biological sample and its position on the array is known, the identification of a patient that has been infected with HCV can be rapidly determined. These approaches are also easily automated using technology known to those of skill in the art of high throughput diagnostic analysis.

Any addressable array technology known in the art can be employed. One particular embodiment of polynucleotide arrays is known as Genechips™, and has been generally described in US Patent 5,143,854; PCT publications WO 90/15070 and 92/10092, all of which are herein expressly incorporated by reference in their entireties. These arrays are generally produced using mechanical synthesis methods or light directed synthesis methods, which incorporate a combination of photolithographic methods and solid phase oligonucleotide synthesis. (Fodor et al., *Science,* 251:767-777, (1991)). The immobilization of arrays of oligonucleotides on solid supports has been rendered possible by the development of a technology generally identified as "Very Large Scale Immobilized Polymer Synthesis" (VLSPIS™) in which, typically, probes are immobilized in a high density array on a solid surface of a chip. Examples of VLSPIS™ technologies are provided in US Patents 5,143,854 and 5,412,087 and in PCT Publications WO 90/15070, WO 92/10092 and WO 95/11995, which describe methods for forming oligonucleotide arrays through techniques such as light-directed synthesis techniques, all of which are herein expressly incorporated by reference in their entireties. In designing strategies aimed at providing arrays of nucleotides immobilized on solid supports, further presentation strategies were developed to order and display the oligonucleotide arrays on the chips in an attempt to maximize hybridization patterns

and diagnostic information. Examples of such presentation strategies are disclosed in PCT Publications WO 94/12305, WO 94/11530, WO 97/29212, and WO 97/31256, all of which are herein expressly incorporated by reference in their entireties.

A wide variety of labels and conjugation techniques are known by those skilled in the art and can be used in various nucleic acid assays. There are several ways to produce labeled nucleic acids for hybridization or PCR including, but not limited to, oligolabeling, nick translation, end-labeling, or PCR amplification using a labeled nucleotide. Alternatively, a nucleic acid encoding an HCV peptide can be cloned into a vector for the production of an mRNA probe. Such vectors are known in the art, are commercially available, and can be used to synthesize RNA probes *in vitro* by addition of an appropriate RNA polymerase such as T7, T3 or SP6 and labeled nucleotides. A number of companies such as Pharmacia Biotech (Piscataway N.J.), Promega (Madison Wis.), and U.S. Biochemical Corp (Cleveland Ohio) supply commercial kits and protocols for these procedures. Suitable reporter molecules or labels include those radionuclides, enzymes, fluorescent, chemiluminescent, or chromogenic agents, as well as, substrates, cofactors, inhibitors, magnetic particles and the like.

The presence of an HCV peptide in a protein sample obtained from a patient can also be detected by using conventional assays and the embodiments described herein. For example, antibodies that are immunoreactive with the disclosed HCV peptides can be used to screen biological samples for the presence of HCV infection. In preferred embodiments, antibodies that are reactive to the embodied HCV peptides are used to immunoprecipitate the disclosed HCV peptides from biological samples or are used to react with proteins obtained from a biological sample on Western or Immunoblots. Favored diagnostic embodiments also include enzyme-linked immunosorbant assays (ELISA), radioimmunoassays (RIA), immunoradiometric assays (IRMA) and immunoenzymatic assays (IEMA), including sandwich assays using monoclonal and/or polyclonal antibodies specific for the disclosed HCV peptides. Exemplary sandwich assays are described by David et al., in U.S. Patent Nos. 4,376,110 and 4,486,530, hereby incorporated by reference. Other embodiments employ aspects of the immune-strip technology disclosed in U.S. Patent Nos. 5,290,678; 5,604,105; 5,710,008; 5,744,358; and 5,747,274, herein incorporated by reference.

In another preferred protein-based diagnostic, the antibodies described herein are attached to a support in an ordered array, wherein a plurality of antibodies are attached to distinct regions of the support that do not overlap with each other. As with the nucleic acid-based arrays, the protein-based arrays are ordered arrays that are designed to be "addressable" such that the distinct locations are recorded and can be accessed as part of an assay procedure. These probes are joined to a support in different known locations. The knowledge of the precise location of each probe makes these "addressable" arrays particularly useful in binding assays. For example, an addressable array can comprise a support having several regions to which are joined a plurality of antibody probes that specifically recognize HCV peptides present in a biological sample and differentiate the isotype of HCV identified herein.

By one approach, proteins are obtained from biological samples and are then labeled by conventional approaches (e.g., radioactivity, colorimetrically, or fluorescently). The labeled samples are then applied to the array under conditions that permit binding. If a protein in the sample binds to an antibody probe on the array, then a signal will be detected at a position on the support that corresponds to the location of the antibody-protein complex. Since the identity of each labeled sample is known and the region of the support on which the labeled sample was applied is known, an identification of the presence, concentration, and/or expression level can be rapidly determined. That is, by employing labeled standards of a known concentration of HCV peptide, an investigator can accurately determine the protein concentration of the particular peptide in a tested sample and can also assess the expression level of the HCV peptide. Conventional methods in densitometry can also be used to more accurately determine the concentration or expression level of the HCV peptide. These approaches are easily automated using technology known to those of skill in the art of high throughput diagnostic analysis.

In another embodiment, an approach opposite to that presented above can be employed. Proteins present in biological samples can be disposed on a support so as to create an addressable array. Preferably, the protein samples are disposed on the support at known positions that do not overlap. The presence of an HCV peptide in each sample is then determined by applying labeled antibody probes that recognize epitopes specific

for the HCV peptide. Because the identity of the biological sample and its position on the array is known, an identification of the presence, concentration, and/or expression level of an HCV peptide can be rapidly determined.

That is, by employing labeled standards of a known concentration of HCV peptide, an investigator can accurately determine the concentration of peptide in a sample and from this information can assess the expression level of the peptide. Conventional methods in densitometry can also be used to more accurately determine the concentration or expression level of the HCV peptide. These approaches are also easily automated using technology known to those of skill in the art of high throughput diagnostic analysis. As detailed above, any addressable array technology known in the art can be employed. The next section describes more compositions that involve the embodied HCV nucleic acids and/or HCV peptides.

Compositions comprising HCV nucleic acids or peptides

Embodiments of the invention also include NS3/4A fusion proteins or nucleic acids encoding these molecules. For instance, production and purification of recombinant protein may be facilitated by the addition of auxiliary amino acids to form a "tag". Such tags include, but are not limited to, His-6, Flag, Myc and GST. The tags may be added to the C-terminus, N-terminus, or within the NS3/4A amino acid sequence. Further embodiments include NS3/4A fusion proteins with amino or carboxy terminal truncations, or internal deletions, or with additional polypeptide sequences added to the amino or carboxy terminal ends, or added internally. Other embodiments include NS3/4A fusion proteins, or truncated or mutated versions thereof, where the residues of the NS3/4A proteolytic cleavage site have been substituted. Such substitutions include, but are not limited to, sequences where the P1′ site is a Ser, Gly, or Pro, or the P1 position is an Arg, or where the P8 to P4′ sequence is Ser-Ala-Asp-Leu-Glu-Val-Val-Thr-Ser-Thr-Trp-Val (**SEQ. ID. NO.: 15**).

More embodiments concern an immunogen comprising the NS3/4A fusion protein, or a truncated, mutated, or modified version thereof, capable of eliciting an enhanced immune response against NS3. The immunogen can be provided in a substantially purified form, which means that the immunogen has been rendered

substantially free of other proteins, lipids, carbohydrates or other compounds with which it naturally associates.

Some embodiments contain at least one of the HCV nucleic acids or HCV peptides (e.g., **SEQ. ID. NOs.: 1-27**) joined to a support. Preferably, these supports are manufactured so as to create a multimeric agent. These multimeric agents provide the HCV peptide or nucleic acid in such a form or in such a way that a sufficient affinity to the molecule is achieved. A multimeric agent having an HCV nucleic acid or peptide can be obtained by joining the desired molecule to a macromolecular support. A "support" can be a termed a carrier, a protein, a resin, a cell membrane, or any macromolecular structure used to join or immobilize such molecules. Solid supports include, but are not limited to, the walls of wells of a reaction tray, test tubes, polystyrene beads, magnetic beads, nitrocellulose strips, membranes, microparticles such as latex particles, animal cells, Duracyte®, artificial cells, and others. An HCV nucleic acid or peptide can also be joined to inorganic carriers, such as silicon oxide material (e.g., silica gel, zeolite, diatomaceous earth or aminated glass) by, for example, a covalent linkage through a hydroxy, carboxy or amino group and a reactive group on the carrier.

In several multimeric agents, the macromolecular support has a hydrophobic surface that interacts with a portion of the HCV nucleic acid or peptide by a hydrophobic non-covalent interaction. In some cases, the hydrophobic surface of the support is a polymer such as plastic or any other polymer in which hydrophobic groups have been linked such as polystyrene, polyethylene or polyvinyl. Additionally, HCV nucleic acid or peptide can be covalently bound to carriers including proteins and oligo/polysaccarides (e.g. cellulose, starch, glycogen, chitosane or aminated sepharose). In these later multimeric agents, a reactive group on the molecule, such as a hydroxy or an amino group, is used to join to a reactive group on the carrier so as to create the covalent bond. Additional multimeric agents comprise a support that has other reactive groups that are chemically activated so as to attach the HCV nucleic acid or peptide. For example, cyanogen bromide activated matrices, epoxy activated matrices, thio and thiopropyl gels, nitrophenyl chloroformate and N-hydroxy succinimide chlorformate linkages, or oxirane acrylic supports are used. (Sigma).

Carriers for use in the body, (i.e. for prophylactic or therapeutic applications) are desirably physiological, non-toxic and preferably, non-immunoresponsive. Suitable carriers for use in the body include poly-L-lysine, poly-D, L-alanine, liposomes, and Chromosorb® (Johns-Manville Products, Denver Co.). Ligand conjugated Chromosorb® (Synsorb-Pk) has been tested in humans for the prevention of hemolytic-uremic syndrome and was reported as not presenting adverse reactions. *(Armstrong et al. J. Infectious Diseases 171:1042-1045 (1995))*. For some embodiments, a "naked" carrier (i.e., lacking an attached HCV nucleic acid or peptide) that has the capacity to attach an HCV nucleic acid or peptide in the body of a organism is administered. By this approach, a "prodrug-type" therapy is envisioned in which the naked carrier is administered separately from the HCV nucleic acid or peptide and, once both are in the body of the organism, the carrier and the HCV nucleic acid or peptide are assembled into a multimeric complex.

The insertion of linkers, such as linkers (e.g., "λ linkers" engineered to resemble the flexible regions of λ phage) of an appropriate length between the HCV nucleic acid or peptide and the support are also contemplated so as to encourage greater flexibility of the HCV peptide, hybrid, or binding partner and thereby overcome any steric hindrance that can be presented by the support. The determination of an appropriate length of linker that allows for an optimal cellular response or lack thereof, can be determined by screening the HCV nucleic acid or peptide with varying linkers in the assays detailed in the present disclosure.

A composite support comprising more than one type of HCV nucleic acid or peptide is also envisioned. A "composite support" can be a carrier, a resin, or any macromolecular structure used to attach or immobilize two or more different HCV nucleic acids or peptides. As above, the insertion of linkers, such as λ linkers, of an appropriate length between the HCV nucleic acid or peptide and the support is also contemplated so as to encourage greater flexibility in the molecule and thereby overcome any steric hindrance that can occur. The determination of an appropriate length of linker that allows for an optimal cellular response or lack thereof, can be determined by screening the HCV nucleic acid or peptide with varying linkers in the assays detailed in the present disclosure.

In other embodiments, the multimeric and composite supports discussed above can have attached multimerized HCV nucleic acids or peptides so as to create a "multimerized-multimeric support" and a "multimerized-composite support", respectively. A multimerized ligand can, for example, be obtained by coupling two or more HCV nucleic acids or peptides in tandem using conventional techniques in molecular biology. The multimerized form of the HCV nucleic acid or peptide can be advantageous for many applications because of the ability to obtain an agent with a higher affinity, for example. The incorporation of linkers or spacers, such as flexible λ linkers, between the individual domains that make-up the multimerized agent can also be advantageous for some embodiments. The insertion of λ linkers of an appropriate length between protein binding domains, for example, can encourage greater flexibility in the molecule and can overcome steric hindrance. Similarly, the insertion of linkers between the multimerized HCV nucleic acid or peptide and the support can encourage greater flexibility and limit steric hindrance presented by the support. The determination of an appropriate length of linker can be determined by screening the HCV nucleic acids or peptides in the assays detailed in this disclosure.

Embodiments also include vaccine compositions comprising the NS3/4A fusion protein, or a truncated or mutated version thereof, and, optionally, an adjuvant. The next section describes some of the preferred vaccine compositions in greater detail.

Vaccine compositions

Vaccine compositions comprising either an embodied HCV nucleic acid or HCV peptide or both (e.g., any one or more of **SEQ. ID. NOs.: 1-27** are contemplated. These compositions typically contain an adjuvant, but do not necessarily require an adjuvant. That is many of the nucleic acids and peptides described herein function as immunogens when administered neat. The compositions described herein (e.g., the HCV immunogens and vaccine compositions containing an adjuvant, such as ribavirin) can be manufactured in accordance with conventional methods of galenic pharmacy to produce medicinal agents for administration to animals, e.g., mammals including humans.

Various nucleic acid-based vaccines are known and it is contemplated that these compositions and approaches to immunotherapy can be augmented by reformulation

with ribavirin (See e.g., U.S. Pat. No. 5,589,466 and 6,235,888, both of which are herein expressly incorporated by reference in their entireties). By one approach, for example, a gene encoding one of the HCV peptides described herein (e.g., **SEQ. ID. NO.: 1**) is cloned into an expression vector capable of expressing the polypeptide when introduced into a subject. The expression construct is introduced into the subject in a mixture of adjuvant (e.g., ribavirin) or in conjunction with an adjuvant (e.g., ribavirin). For example, the adjuvant (e.g., ribavirin) is administered shortly after the expression construct at the same site. Alternatively, RNA encoding the HCV polypeptide antigen of interest is provided to the subject in a mixture with ribavirin or in conjunction with an adjuvant (e.g., ribavirin).

Where the antigen is to be DNA (e.g., preparation of a DNA vaccine composition), suitable promoters include Simian Virus 40 (SV40), Mouse Mammary Tumor Virus (MMTV) promoter, Human Immunodeficiency Virus (HIV) such as the HIV Long Terminal Repeat (LTR) promoter, Moloney virus, ALV, Cytomegalovirus (CMV) such as the CMV immediate early promoter, Epstein Barr Virus (EBV), Rous Sarcoma Virus (RSV) as well as promoters from human genes such as human actin, human myosin, human hemoglobin, human muscle creatine and human metalothionein can be used. Examples of polyadenylation signals useful with some embodiments, especially in the production of a genetic vaccine for humans, include but are not limited to, SV40 polyadenylation signals and LTR polyadenylation signals. In particular, the SV40 polyadenylation signal, which is in pCEP4 plasmid (Invitrogen, San Diego Calif.), referred to as the SV40 polyadenylation signal, is used.

In addition to the regulatory elements required for gene expression, other elements may also be included in a gene construct. Such additional elements include enhancers. The enhancer may be selected from the group including but not limited to: human actin, human myosin, human hemoglobin, human muscle creatine and viral enhancers such as those from CMV, RSV and EBV. Gene constructs can be provided with mammalian origin of replication in order to maintain the construct extrachromosomally and produce multiple copies of the construct in the cell. Plasmids pCEP4 and pREP4 from Invitrogen (San Diego, CA) contain the Epstein Barr virus origin of replication and nuclear antigen EBNA-1 coding region, which produces high

copy episomal replication without integration. All forms of DNA, whether replicating or non-replicating, which do not become integrated into the genome, and which are expressible, can be used. Preferably, the genetic vaccines comprise ribavirin and a nucleic acid encoding NS3/4A, NS3, or a fragment or mutant thereof (**SEQ. ID. NOs.: 2-26**). The following example describes the preparation of a genetic vaccine suitable for use in humans.

EXAMPLE 9

An HCV expression plasmid is designed to express the NS3/4A peptide (**SEQ. ID. NO.: 2**). The NS3/4A coding sequence of NS3/4A-pVAX is removed by digestion with *EcoRI* and *XbaI*, and the isolated fragment is inserted into plasmid A so that it is under the transcriptional control of the CMV promoter and the RSV enhancer element. (*See* U.S. Pat. No. 6,235,888 to Pachuk , et al., herein expressly incorporated by reference in its entirety). Plasmid Plasmid backbone A is 3969 base pairs in length; it contains a PBR origin of replication for replicating in *E. coli* and a kanamycin resistance gene. Inserts such as the NS3/4A, are cloned into a polylinker region, which places the insert between and operably linked to the promoter and polyadenylation signal. Transcription of the cloned inserts is under the control of the CMV promoter and the RSV enhancer elements. A polyadenylation signal is provided by the presence of an SV40 poly A signal situated just 3' of the cloning site. An NS3/4A containing vaccine composition is then made by mixing 500μg of the rNS3/4A construct with 1mg of ribavirin.

Said vaccine composition can be used to raise antibodies in a mammal (e.g., mice or rabbits) or can be injected intramuscularly into a human so as to to raise antibodies, preferably a human that is chronically infected with the HCV virus. The recipient preferably receives three immunization boosts of the mixture at 4-week intervals, as well. By the third boost, the titer of antibody specific for HCV will be significantly increased. Additionally, at this time, said subject will experience an enhanced antibody and T-cell mediated immune response against NS3, as evidenced by an increased fraction of NS3 specific antibodies as detected by EIA, and a reduction in viral load as detected by RT-PCR.

Also contemplated are vaccine compositions comprising one or more of the HCV peptides described herein. Preferably, the embodied peptide vaccines comprise ribavirin and NS3/4A, NS3, or a fragment or mutant thereof (e.g., **SEQ. ID. NOs.: 2-26**). The following example describes an approach to prepare a vaccine composition comprising an NS3/4A fusion protein and an adjuvant.

EXAMPLE 10

To generate a tagged NS3/4A construct, the NS3/4A coding sequence of NS3/4A-pVAX is removed by digestion with *EcoRI* and *XbaI*, and the isolated fragment is inserted into an Xpress vector (Invitrogen). The Xpress vector allows for the production of a recombinant fusion protein having a short N-terminal leader peptide that has a high affinity for divalent cations. Using a nickel-chelating resin (Invitrogen), the recombinant protein can be purified in one step and the leader can be subsequently removed by cleavage with enterokinase. A preferred vector is the pBlueBacHis2 Xpress. The pBlueBacHis2 Xpress vector is a *Baculovirus* expression vector containing a multiple cloning site, an ampicillin resistance gene, and a *lac z* gene. Accordingly, the digested amplification fragment is cloned into the pBlueBacHis2 Xpress vector and SF9 cells are infected. The expression protein is then isolated or purified according to the manufacturer's instructions. An NS3/4A containing vaccine composition is then made by mixing 100µg of the rNS3/4A with 1mg of ribavirin.

Said vaccine composition can be used to raise antibodies in a mammal (e.g., mice or rabbits) or can be injected intramuscularly into a human so as to to raise antibodies, preferably a human that is chronically infected with the HCV virus. The recipient preferably receives three immunization boosts of the mixture at 4-week intervals. By the third boost, the titer of antibody specific for HCV will be significantly increased. Additionally, at this time, said subject will experience an enhanced antibody and T-cell mediated immune response against NS3, as evidenced by an increased fraction of NS3 specific antibodies as detected by EIA, and a reduction in viral load as detected by RT-PCR.

The compositions (e.g., vaccines) that comprise one or more of the embodied HCV nucleic acids or peptides may contain other ingredients including, but not limited

to, adjuvants (e.g., ribavirin), binding agents, excipients such as stabilizers (to promote long term storage), emulsifiers, thickening agents, salts, preservatives, solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents and the like. These compositions are suitable for treatment of animals either as a preventive measure to avoid a disease or condition or as a therapeutic to treat animals already afflicted with a disease or condition.

Many other ingredients can be also be present. For example, the adjuvant (e.g., ribavirin) and antigen can be employed in admixture with conventional excipients (e.g., pharmaceutically acceptable organic or inorganic carrier substances suitable for parenteral, enteral (e.g., oral) or topical application that do not deleteriously react with the ribavirin and/or antigen). Suitable pharmaceutically acceptable carriers include, but are not limited to, water, salt solutions, alcohols, gum arabic, vegetable oils, benzyl alcohols, polyetylene glycols, gelatine, carbohydrates such as lactose, amylose or starch, magnesium stearate, talc, silicic acid, viscous paraffin, perfume oil, fatty acid monoglycerides and diglycerides, pentaerythritol fatty acid esters, hydroxy methylcellulose, polyvinyl pyrrolidone, etc. Many more suitable carriers are described in *Remmington's* Pharmaceutical Sciences, 15th Edition, Easton:Mack Publishing Company, pages 1405-1412 and 1461-1487(1975) and The National *Formulary* XIV, 14th Edition, Washington, American Pharmaceutical Association (1975), herein expressly incorporated by reference in their entireties.

The gene constructs described herein, in particular, may be formulated with or administered in conjunction with agents that increase uptake and/or expression of the gene construct by the cells relative to uptake and/or expression of the gene construct by the cells that occurs when the identical genetic vaccine is administered in the absence of such agents. Such agents and the protocols for administering them in conjunction with gene constructs are described in PCT Patent Application Serial Number PCT/US94/00899 filed Jan. 26, 1994, which is incorporated herein by reference. Examples of such agents include: $CaPO_4$, DEAE dextran, anionic lipids; extracellular matrix-active enzymes; saponins; lectins; estrogenic compounds and steroidal hormones; hydroxylated lower alkyls; dimethyl sulfoxide (DMSO); urea; and benzoic acid esters anilides, amidines, urethanes and the hydrochloride salts thereof such as

those of the family of local anesthetics. In addition, the gene constructs are encapsulated within/administered in conjunction with lipids/polycationic complexes.

Vaccines can be sterilized and if desired mixed with auxiliary agents, e.g., lubricants, preservatives, stabilizers, wetting agents, emulsifiers, salts for influencing osmotic pressure, buffers, coloring, flavoring and/or aromatic substances and the like that do not deleteriously react with the adjuvant (e.g., ribavirin) or the HCV nucleic acid or peptide.

The effective dose and method of administration of a particular vaccine formulation can vary based on the individual patient and the type and stage of the disease, as well as other factors known to those of skill in the art. Therapeutic efficacy and toxicity of the vaccines can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, e.g., ED_{50} (the dose therapeutically effective in 50% of the population). The data obtained from cell culture assays and animal studies can be used to formulate a range of dosage for human use. The dosage of the vaccines lies preferably within a range of circulating concentrations that include the ED_{50} with no toxicity. The dosage varies within this range depending upon the type of adjuvant derivative and HCV antigen, the dosage form employed, the sensitivity of the patient, and the route of administration.

Since many adjuvants, including ribavirin, has been on the market for several years, many dosage forms and routes of administration are known. All known dosage forms and routes of administration can be provided within the context of the embodiments described herein. Preferably, an amount of adjuvant (e.g., ribavirin) that is effective to enhance an immune response to an antigen in an animal can be considered to be an amount that is sufficient to achieve a blood serum level of antigen approximately 0.25 - 12.5μg/ml in the animal, preferably, about 2.5μg/ml. In some embodiments, the amount of adjuvant (e.g., ribavirin) is determined according to the body weight of the animal to be given the vaccine. Accordingly, the amount of adjuvant (e.g., ribavirin) in a vaccine formulation can be from about 0.1 - 6.0mg/kg body weight. That is, some embodiments have an amount of adjuvant (e.g., ribavirin) that corresponds to approximately 0.1 - 1.0mg/kg, 1.1 - 2.0mg/kg, 2.1 - 3.0mg/kg, 3.1 - 4.0mg/kg, 4.1 - 5.0mg/kg, 5.1, and 6.0mg/kg body weight of an animal. More

conventionally, the vaccines contain approximately 0.25mg - 2000mg of adjuvant (e.g., ribavirin). That is, some embodiments have approximately 250μg, 500μg, 1mg, 25mg, 50mg, 100mg, 150mg, 200mg, 250mg, 300mg, 350mg, 400mg, 450mg, 500mg, 550mg, 600mg, 650mg, 700mg, 750mg, 800mg, 850mg, 900mg, 1g, 1.1g, 1.2g, 1.3g, 1.4g, 1.5g, 1.6g, 1.7g, 1.8g, 1.9g, and 2g of adjuvant (e.g., ribavirin).

As one of skill in the art will appreciate, the amount of antigens in a vaccine can vary depending on the type of antigen and its immunogenicity. The amount of antigens in the vaccines can vary accordingly. Nevertheless, as a general guide, the vaccines can have approximately 0.25mg - 5mg, 5-10mg, 10-100mg, 100-500mg, and upwards of 2000mg of an HCV antigen described herein. Preferably, the amount of HCV antigen is 0.1μg - 1mg, desirably, 1μg-100μg, preferably 5μg-50μg, and, most preferably, 7μg, 8μg, 9μg, 10μg, 11μg-20μg, when said antigen is a nucleic acid and 1μg-100mg, desirably, 10μg-10mg, preferably, 100μg-1mg, and, most preferably, 200μg, 300μg, 400μg, 500μg, 600μg, or 700μg-1mg, when said antigen is a peptide.

In some approaches described herein, the exact amount of adjuvant (e.g., ribavirin) and/or HCV antigen is chosen by the individual physician in view of the patient to be treated. Further, the amounts of ribavirin can be added in combination to or separately from the same or equivalent amount of antigen and these amounts can be adjusted during a particular vaccination protocol so as to provide sufficient levels in light of patient-specific or antigen-specific considerations. In this vein, patient-specific and antigen-specific factors that can be taken into account include, but are not limited to, the severity of the disease state of the patient, age, and weight of the patient, diet, time and frequency of administration, drug combination(s), reaction sensitivities, and tolerance/response to therapy. The next section describes the discovery that ribavirin is an effective adjuvant.

Ribavirin

Nucleoside analogs have been widely used in anti-viral therapies due to their capacity to reduce viral replication. (Hosoya et al., *J. Inf. Dis.*, 168:641-646 (1993)). ribavirin (1-β-D-ribofuranosyl-1,2,4-triazole-3-carboxamide) is a synthetic guanosine analog that has been used to inhibit RNA and DNA virus replication. (Huffman et al.,

Antimicrob. Agents. Chemother., 3:235 (1973); Sidwell et al., *Science*, 177:705 (1972)). Ribavirin has been shown to be a competitive inhibitor of inositol mono-phosphate (IMP) dehydrogenase (IMPDH), which converts IMP to IMX (which is then converted to GMP). De Clercq, Anti viral Agents: characteristic activity spectrum depending on the molecular target with which they interact, Academic press, Inc., New York N.Y., pp. 1-55 (1993). Intracellular pools of GTP become depleted as a result of long term ribavirin treatment.

In addition to antiviral activity, investigators have observed that some guanosine analogs have an effect on the immune system. (U.S. Patent Nos. 6,063,772 and 4,950,647). Ribavirin has been shown to inhibit functional humoral immune responses (Peavy et al., *J. Immunol.*, 126:861-864 (1981); Powers et al., *Antimicrob. Agents. Chemother.*, 22:108-114 (1982)) and IgE-mediated modulation of mast cell secretion. (Marquardt et al., *J. Pharmacol. Exp. Therapeutics*, 240:145-149 (1987)). Some investigators report that a daily oral therapy of ribavirin has an immune modulating effect on humans and mice. (Hultgren et al., *J. Gen. Virol.*, 79:2381-2391 (1998) and Cramp et al., *Gastron. Enterol.*, 118:346-355 (2000)). Nevertheless, the current understanding of the effects of ribavirin on the immune system is in its infancy. As disclosed in *Examples 9-12,* ribavirin was found to be a potent adjuvant.

EXAMPLE 11

In a first set of experiments, groups of three to five Balb/c mice (BK Universal, Uppsala, Sweden) were immunized *i.p* or *s.c.* (e.g., at the base of the tail) with 10μg or 100μg of recombinant hepatitis C virus non-structural 3 (rNS3) protein. The rNS3 was dissolved in phosphate buffered saline (PBS) alone or PBS containing 1mg ribavirin (obtained from ICN, Costa Mesa, CA). Mice were injected with a total volume of 100μl per injection.

At two and four weeks following *i.p.* immunization, all mice were bled by retro-orbital sampling. Serum samples were collected and analyzed for the presence of antibodies to rNS3. To determine the antibody titer, an enzyme immunoassay (EIA) was performed. (See e.g., Hultgren et al., *J Gen Virol.* 79:2381-91 (1998) and Hultgren et al., *Clin. Diagn. Lab. Immunol.* 4:630-632 (1997), both of which are herein expressly

incorporated by reference in their entireties). The antibody levels were recorded as the highest serum dilution giving an optical density at 405nm more than twice that of non-immunized mice.

Mice that received 10μg or 100μg rNS3 mixed with 1mg ribavirin in PBS displayed consistently higher levels of NS3 antibodies. The antibody titer that was detected by EIA at two weeks post-immunization is shown in **FIGURE 3**. The vaccine formulations having 1mg of ribavirin and either 10μg or 100μg of rNS3 induced a significantly greater antibody titer than the vaccine formulations composed of only rNS3.

In a second set of experiments, groups of eight Balb/c mice were immunized intraperitoneally with 10 or 50 μg of rNS3 in 100 μl phosphate buffered saline containing either 0 mg, 1 mg, 3 mg, or 10 mg ribavirin (Sigma). At four, six and eight weeks the mice were bled and serum was separated and frozen. After completion of the study, sera were tested for the levels of antibodies to recombinant NS3, as described above. Mean antibody levels to rNS3 were compared between the groups using Student's t-test (parametric analysis) or Mann-Whitney (non-parametric analysis) and the software package StatView 4.5 (Abacus Concepts, Berkely, CA). The adjuvant effect of ribavirin when added in three doses to 10 μg of rNS3 are provided in **TABLE 7**. The adjuvant effect of ribavirin when added in three doses to 50 μg of rNS3 are provided in **TABLE 7**. Parametrical comparison of the mean rNS3 antibody titres in mice receiving different 10μg or 50 μg of rNS3 and different doses of ribavirin are provided in **TABLES 8** and **9**, respectively. Non-parametrical comparison of mean NS3 antibody titres in mice receiving different 10μg or 50 μg of rNS3 and different doses of ribavirin are provided in **TABLES 10** and **11**, respectively. The values given represent end point titres to recombinant rNS3.

TABLE 7

Amount ribavirin (mg/dose)	Amount immunogen (μg/dose)	Mouse ID	Antibody titre to rNS3 at indicated week		
			Week 4	Week 6	Week 8

None	10	5:1	300	1500	1500
None	10	5:2	<60	7500	1500
None	10	5:3	<60	1500	300
None	10	5:4	60	1500	1500
None	10	5:5	<60	1500	nt
None	10	5:6	60	1500	1500
None	10	5:7	<60	7500	7500
None	10	5:8	300	37500	7500
Group mean titre (mean±SD)			180 ±139	7500 ±12421	3042 ±3076
1	10	6:1	300	37500	37500
1	10	6:2	<60	1500	1500
1	10	6:3	300	37500	187500
1	10	6:4	300	37500	7500
1	10	6:5	60	nt	nt
1	10	6:6	<60	37500	7500
1	10	6:7	<60	37500	7500
1	10	6:8	300	7500	7500
Group mean titre (mean±SD)			252 ±107	28071 ±16195	36642 ±67565
3	10	7:1	60	37500	7500
3	10	7:2	60	37500	37500
3	10	7:3	300	7500	7500
3	10	7:4	300	37500	7500
3	10	7:5	300	37500	37500
3	10	7:6	300	37500	37500
3	10	7:7	60	7500	7500
3	10	7:8	60	37500	37500
Group mean titre (mean±SD)			180± 128	30000± 13887	22500± 34637
10	10	8:1	300	37500	37500
10	10	8:2	300	37500	37500
10	10	8:3	<60	300	300
10	10	8:4	60	7500	7500
10	10	8:5	<60	300	300
10	10	8:6	<60	37500	37500
10	10	8:7	<60	7500	7500
10	10	8:8	<60	nt	nt
Group mean titre (mean±SD)			220± 139	18300± 18199	18300± 18199

TABLE 8

Amount ribavirin (mg/dose)	Amount immunogen (μg/dose)	Mouse ID	Antibody titre to rNS3 at indicated week		
			Week 4	Week 6	Week 8
None	50	1:1	60	7500	7500
None	50	1:2	60	7500	7500
None	50	1:3	60	7500	7500
None	50	1:4	<60	1500	300
None	50	1:5	300	37500	37500
None	50	1:6	60	7500	7500
None	50	1:7	60	37500	7500
None	50	1:8	.	.	.
Group mean titre (mean±SD)			100 ±98	15214 ±15380	10757 ±12094
1	50	2:1	60	7500	7500
1	50	2:2	300	37500	7500
1	50	2:3	60	187500	7500
1	50	2:4	60	37500	187500
1	50	2:5	60	37500	7500
1	50	2:6	60	37500	37500
1	50	2:7	300	37500	7500
1	50	2:8	300	37500	37500
Group mean titre (mean±SD)			150 ±124	52500 ±55549	37500 ±62105
3	50	3:1	60	37500	7500
3	50	3:2	300	37500	37500
3	50	3:3	300	37500	7500
3	50	3:4	60	37500	7500
3	50	3:5	300	37500	7500
3	50	3:6	60	37500	7500
3	50	3:7	-	7500	37500
3	50	3:8	1500	7500	37500
Group mean titre (mean±SD)			387 ±513	30000 ±13887	18750 ±15526
10	50	4:1	300	7500	7500
10	50	4:2	300	37500	37500
10	50	4:3	60	7500	7500
10	50	4:4	60	7500	7500
10	50	4:5	60	1500	1500
10	50	4:6	60	7500	37500
10	50	4:7	-	7500	7500
10	50	8:8	60	37500	7500
Group mean titre (mean±SD)			140 ±124	10929 ±11928	15214 ±15380

TABLE 9

Group	Week	Mean±SD	Group	Mean±SD	analysis	p-value
10μg NS3/no ribavirin	4	180 ±139	10 μg NS3/ 1 mg ribavirin	252 ±107	Students t-test	0.4071
	6	7500 ±12421		28071 ±16195	Students t-test	0.0156*
	8	3042 ±3076		36642 ±67565	Students t-test	0.2133
10μg NS3/no ribavirin	4	180 ±139	10 μg NS3/ 3 mg ribavirin	180± 128	Students t-test	1.000
	6	7500 ±12421		30000± 13887	Students t-test	0.0042**
	8	3042 ±3076		22500± 34637	Students t-test	0.0077**
10μg NS3/no ribavirin	4	180 ±139	10 μg NS3/ 10mg ribavirin	220± 139	Students t-test	0.7210
	6	7500 ±12421		18300± 18199	Students t-test	0.1974
	8	3042 ±3076		18300± 18199	Students t-test	0.0493*

TABLE10

Group	Week	Mean±SD	Group	Mean±SD	analysis	p-value
50μg NS3/no ribavirin	4	100 ±98	50 μg NS3/ 1 mg ribavirin	150 ±124	Students t-test	0.4326
	6	15214 ±15380		52500 ±55549	Students t-test	0.1106
	8	10757 ±12094		37500 ±62105	Students t-test	0.2847
50μg NS3/no ribavirin	4	100 ±98	50 μg NS3/ 3 mg ribavirin	387 ±513	Students t-test	0.2355
	6	15214 ±15380		30000 ±13887	Students t-test	0.0721
	8	10757 ±12094		18750 ±15526	Students t-test	0.2915
50μg NS3/no ribavirin	4	100 ±98	50 μg NS3/ 10mg ribavirin	140 ±124	Students t-test	0.5490

	6	15214 ±15380		10929 ±11928	Students t-test	0.5710
	8	10757 ±12094		15214 ±15380	Students t-test	0.5579

Significance levels: NS = not significant; * = p<0.05; ** = p<0.01; *** = p<0.001

TABLE 11

Group	Week	Mean±SD	Group	Mean±SD	analysis	p-value
10μg NS3/no ribavirin	4	180 ±139	10 μg NS3/ 1 mg ribavirin	252 ±107	Mann-Whitney	0.4280
	6	7500 ±12421		28071 ±16195	Mann-Whitney	0.0253*
	8	3042 ±3076		36642 ±67565	Mann-Whitney	0.0245*
10μg NS3/no ribavirin	4	180 ±139	10 μg NS3/ 3 mg ribavirin	180± 128	Mann-Whitney	0.0736
	6	7500 ±12421		30000± 13887	Mann-Whitney	0.0050**
	8	3042 ±3076		22500± 34637	Mann-Whitney	0.0034**
10μg NS3/no ribavirin	4	180 ±139	10 μg NS3/ 10mg ribavirin	220± 139	Mann-Whitney	0.8986
	6	7500 ±12421		18300± 18199	Mann-Whitney	0.4346
	8	3042 ±3076		18300± 18199	Mann-Whitney	0.2102

TABLE 12

Group	Week	Mean±SD	Group	Mean±SD	analysis	p-value
50μg NS3/no ribavirin	4	100 ±98	50 μg NS3/ 1 mg ribavirin	150 ±124	Mann-Whitney	0.1128
	6	15214 ±15380		52500 ±55549	Mann-Whitney	0.0210*
	8	10757 ±12094		37500 ±62105	Mann-Whitney	0.1883
50μg NS3/no ribavirin	4	100 ±98	50 μg NS3/ 3 mg ribavirin	387 ±513	Mann-Whitney	0.1400
	6	15214 ±15380		30000 ±13887	Mann-Whitney	0.0679
	8	10757 ±12094		18750 ±15526	Mann-Whitney	0.2091

50μg NS3/no ribavirin	4	100 ±98	50 μg NS3/ 10 mg ribavirin	140 ±124	Mann-Whitney	0.4292
	6	15214 ±15380		10929 ±11928	Mann-Whitney	0.9473
	8	10757 ±12094		15214 ±15380	Mann-Whitney	0.6279

Significance levels: NS = not significant; * = p<0.05; ** = p<0.01; *** = p<0.001

The data above demonstrates that ribavirin facilitates or enhances an immune response to an HCV antigen or HCV epitopes. A potent immune response to rNS3 was elicited after immunization with a vaccine composition comprising as little as 1 mg ribavirin and 10 μg of rNS3 antigen. The data above also provide evidence that the amount of ribavirin that is sufficient to facilitate an immune response to an antigen is between 1 and 3 mg per injection for a 25-30g Balb/c mouse. It should be realized, however, that these amounts are intended for guidance only and should not be interpreted to limit the scope of the invention in any way. Nevertheless, the data shows that vaccine compositions comprising approximately 1 to 3 mg doses of ribavirin induce an immune response that is more than 12 times higher than the immune response elicited in the absence of without ribavirin. Thus, ribavirin has a significant adjuvant effect on the humoral immune response of an animal and thereby, enhances or facilitates the immune response to the antigen. The example below describes experiments that were performed to better understand the amount of ribavirin needed to enhance or facilitate an immune response to an antigen.

EXAMPLE 12

To determine a dose of ribavirin that is sufficient to provide an adjuvant effect, the following experiments were performed. In a first set of experiments, groups of mice (three per group) were immunized with a 20μg rNS3 alone or a mixture of 20μg rNS3 and 0.1mg, 1mg, or 10mg ribavirin. The levels of antibody to the antigen were then determined by EIA. The mean endpoint titers at weeks 1 and 3 were plotted and are shown in **FIGURE 4**. It was discovered that the adjuvant effect provided by ribavirin had different kinetics depending on the dose of ribavirin provided. For example, even low doses (<1mg) of ribavirin were found to enhance antibody levels at week one but

not at week three, whereas, higher doses (1-10mg) were found to enhance antibody levels at week three.

A second set of experiments was also performed. In these experiments, groups of mice were injected with vaccine compositions comprising various amounts of ribavirin and rNS3 and the IgG response in these animals was monitored. The vaccine compositions comprised approximately 100 µl phosphate buffered saline and 20 µg rNS3 with or without 0.1 mg, 1.0 mg, or 10 mg ribavirin (Sigma). The mice were bled at week six and rNS3-specific IgG levels were determined by EIA as described previously. As shown in **TABLE 13**, the adjuvant effects on the sustained antibody levels were most obvious in the dose range of 1 to 10 mg per injection for a 25-30g mouse.

TABLE 13

Immunogen	Amount (mg) ribavirin mixed with the immunogen	Mouse ID	Endpoint titre of rNS3 IgG at indicated week		
			Week 1	Week 2	Week 3
20 µg rNS3	None	1	60	360	360
20 µg rNS3	None	2	360	360	2160
20 µg rNS3	None	3	360	2160	2160
		Mean	260±173	960±1039	1560±1039
20 µg rNS3	0.1	4	2160	12960	2160
20 µg rNS3	0.1	5	60	60	60
20 µg rNS3	0.1	6	<60	2160	2160
			1110±1484	5060±6921	1460±1212
20 µg rNS3	1.0	7	<60	60	12960
20 µg rNS3	1.0	8	<60	2160	2160
20 µg rNS3	1.0	9	360	2160	2160
		Mean	360	1460±1212	5760±6235
20 µg rNS3	10.0	10	360	12960	77760
20 µg rNS3	10.0	11	<60	2160	12960
20 µg rNS3	10.0	12	360	2160	2160
		Mean	360	5760±6235	30960±40888

In a third set of experiments, the adjuvant effect of ribavirin after primary and booster injections was investigated. In these experiments, mice were given two intraperitoneal injections of a vaccine composition comprising 10 µg rNS3 with or without ribavirin and the IgG subclass responses to the antigen was monitored, as before. Accordingly, mice were immunized with 100 µl phosphate buffered containing 10 µg recombinant NS3 alone, with or without 0.1 or 1.0 mg ribavirin (Sigma) at weeks 0 and 4. The mice were bled at week six and NS3-specific IgG subclasses were determined by EIA as described previously. As shown in **TABLE 14**, the addition of ribavirin to the immunogen prior to the injection does not change the IgG subclass response in the NS3-specific immune response. Thus, the adjuvant effect of a vaccine composition comprising ribavirin and an antigen can not be explained by a shift in of the Th1/Th2-balance. It appears that another mechanism may be responsible for the adjuvant effect of ribavirin.

TABLE 14

Immunogen	Amount (mg) ribavirin mixed with the immunogen	Mouse ID	Endpoint titre of indicated NS3 IgG subclass			
			IgG1	IgG2a	IgG2b	IgG3
10 µg rNS3	None	1	360	60	<60	60
10 µg rNS3	None	2	360	<60	<60	60
10 µg rNS3	None	3	2160	60	<60	360
		Mean	960±1039	60	-	160±173
10 µg rNS3	0.1	4	360	<60	<60	60
10 µg rNS3	0.1	5	60	<60	<60	<60
10 µg rNS3	0.1	6	2160	60	60	360
			860±1136	60	60	210±212
10 µg rNS3	1.0	7	2160	<60	<60	60
10 µg rNS3	1.0	8	360	<60	<60	<60
10 µg rNS3	1.0	9	2160	<60	<60	60
		Mean	1560±1039	-	-	60

The data presented in this example further verify that ribavirin can be administered as an adjuvant and establish that that the dose of ribavirin can modulate the kinetics of the adjuvant effect. The example below describes another assay that was performed to evaluate the ability of ribavirin to enhance or facilitate an immune response to an antigen.

EXAMPLE 13

This assay can be used with any ribavirin derivative or combinations of ribavirin derivatives to determine the extent that a particular vaccine formulation modulates a cellular immune response. To determine $CD4^+$ T cell responses to a ribavirin-containing vaccine, groups of mice were immunized *s.c.* with either 100μg rNS3 in PBS or 100μg rNS3 and 1mg ribavirin in PBS. The mice were sacrificed ten days post-immunization and their lymph nodes were harvested and drained. *In vitro* recall assays were then performed. (See e.g., Hultgren et al., *J Gen Virol.* 79:2381-91 (1998) and Hultgren et al., *Clin. Diagn. Lab. Immunol.* 4:630-632 (1997), both of which are herein expressly incorporated by reference in their entireties). The amount of $CD4^+$ T cell proliferation was determined at 96 h of culture by the incorporation of $[^3H]$ thymidine.

As shown in **FIGURE 5**, mice that were immunized with 100μg rNS3 mixed with 1mg ribavirin had a much greater T cell proliferative response than mice that were immunized with 100μg rNS3 in PBS. This data provides more evidence that ribavirin enhances or facilitates a cellular immune response (e.g., by promoting the effective priming of T cells).

Additional experiments were conducted to verify that ribavirin enhances the immune response to commercially available vaccine preparations. The example below describes the use of ribavirin in conjunction with a commercial HBV vaccine preparation.

EXAMPLE 14

The adjuvant effect of ribavirin was tested when mixed with two doses of a commercially available vaccine containing HBsAg and alum. (Engerix, SKB). Approximately 0.2μg or 2μg of Engerix vaccine was mixed with either PBS or 1mg

ribavirin in PBS and the mixtures were injected intra peritoneally into groups of mice (three per group). A booster containing the same mixture was given on week four and all mice were bled on week six. The serum samples were diluted from 1:60 to 1:37500 and the dilutions were tested by EIA, as described above, except that purified human HBsAg was used as the solid phase antigen. As shown in **TABLE 15**, vaccine formulations having ribavirin enhanced the response to 2μg of an existing vaccine despite the fact that the vaccine already contained alum. That is, by adding ribavirin to a suboptimal vaccine dose (i.e., one that does not induce detectable antibodies alone) antibodies became detectable, providing evidence that the addition of ribavirin allows for the use of lower antigen amounts in a vaccine formulation without compromising the immune response.

TABLE 15

Week	End point antibody titer to HBsAg in EIA											
	0.02μg Engerix						0.2μg Engerix					
	No ribavirin			1mg ribavirin			No ribavirin			1mg ribavirin		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
6	<60	<60	<60	<60	<60	<60	<60	<60	<60	300	60	<60

The ribavirin used in the experiments above was obtained from commercial suppliers (e.g., Sigma and ICN). The ribavirin that can be used with the embodiments described herein can also be obtained from commmercial suppliers or can be synthesized. The ribavirin and/or the antigen can be formulated with and without modification. For example, the ribavirin can be modified or derivatized to make a more stable molecule and/or a more potent adjuvant. By one approach, the stability of ribavirin can be enhanced by coupling the molecules to a support such as a hydrophilic polymer (e.g., polyethylene glycol).

Many more ribavirin derivatives can be generated using conventional techniques in rational drug design and combinatorial chemistry. For example, Molecular

Simulations Inc. (MSI), as well as many other suppliers, provide software that allows one of skill to build a combinatorial library of organic molecules. The C2.Analog Builder program, for example, can be integrated with MSI's suite of Cerius2 molecular diversity software to develop a library of ribavirin derivatives that can be used with the embodiments described herein. (See e.g., http://msi.com/life/products/cerius2/index.html, herein expressly incorporated by reference in its entirety).

By one approach, the chemical structure of ribavirin is recorded on a computer readable media and is accessed by one or more modeling software application programs. The C2.Analog Builder program in conjunction with C2Diversity program allows the user to generate a very large virtual library based on the diversity of R-groups for each substituent position, for example. Compounds having the same structure as the modeled ribavirin derivatives created in the virtual library are then made using conventional chemistry or can be obtained from a commercial source.

The newly manufactured ribavirin derivatives can then be screened in assays, which determine the extent of adjuvant activity of the molecule and/or the extent of its ability to modulate of an immune response. Some assays may involve virtual drug screening software, such as C2.Ludi. C2.Ludi is a software program that allows a user to explore databases of molecules (e.g., ribavirin derivatives) for their ability to interact with the active site of a protein of interest (e.g., RAC2 or another GTP binding protein). Based upon predicted interactions discovered with the virtual drug screening software, the ribavirin derivatives can be prioritized for further characterization in conventional assays that determine adjuvant activity and/or the extent of a molecule to modulate an immune response. The section below provides more explanation concerning the methods of using the compositions described herein.

Methods of using the vaccine compositions

Routes of administration of the embodiments described herein include, but are not limited to, transdermal, parenteral, gastrointestinal, transbronchial, and transalveolar. Transdermal administration can be accomplished by application of a cream, rinse, gel, etc. capable of allowing the adjuvant (e.g., ribavirin) and HCV antigen

to penetrate the skin. Parenteral routes of administration include, but are not limited to, electrical or direct injection such as direct injection into a central venous line, intravenous, intramuscular, intraperitoneal, intradermal, or subcutaneous injection. Gastrointestinal routes of administration include, but are not limited to, ingestion and rectal. Transbronchial and transalveolar routes of administration include, but are not limited to, inhalation, either via the mouth or intranasally.

Compositions having the adjuvant (e.g., ribavirin) and HCV antigen that are suitable for transdermal administration include, but are not limited to, pharmaceutically acceptable suspensions, oils, creams, and ointments applied directly to the skin or incorporated into a protective carrier such as a transdermal device ("transdermal patch"). Examples of suitable creams, ointments, etc. can be found, for instance, in the Physician's Desk Reference. Examples of suitable transdermal devices are described, for instance, in U.S. Patent No. 4,818,540 issued April 4, 1989 to Chinen, et al., herein expressly incorporated by reference in its entirety.

Compositions having the adjuvant (e.g., ribavirin) and HCV antigen that are suitable for parenteral administration include, but are not limited to, pharmaceutically acceptable sterile isotonic solutions. Such solutions include, but are not limited to, saline, phosphate buffered saline and oil preparations for injection into a central venous line, intravenous, intramuscular, intraperitoneal, intradermal, or subcutaneous injection.

Compositions having the adjuvant (e.g., ribavirin) and HCV antigen that are suitable for transbronchial and transalveolar administration include, but not limited to, various types of aerosols for inhalation. Devices suitable for transbronchial and transalveolar administration of these are also embodiments. Such devices include, but are not limited to, atomizers and vaporizers. Many forms of currently available atomizers and vaporizers can be readily adapted to deliver vaccines having ribavirin and an antigen.

Compositions having the adjuvant (e.g., ribavirin) and HCV antigen that are suitable for gastrointestinal administration include, but not limited to, pharmaceutically acceptable powders, pills or liquids for ingestion and suppositories for rectal administration.

The gene constructs described herein, in particular, may be administered by means including, but not limited to, traditional syringes, needleless injection devices, or "microprojectile bombardment gene guns". Alternatively, the genetic vaccine may be introduced by various means into cells that are removed from the individual. Such means include, for example, *ex vivo* transfection, electroporation, microinjection and microprojectile bombardment. After the gene construct is taken up by the cells, they are reimplanted into the individual. It is contemplated that otherwise non-immunogenic cells that have gene constructs incorporated therein can be implanted into the individual even if the vaccinated cells were originally taken from another individual.

According to some embodiments, the gene construct is administered to an individual using a needleless injection device. According to some embodiments, the gene construct is simultaneously administered to an individual intradermally, subcutaneously and intramuscularly using a needleless injection device. Needleless injection devices are well known and widely available. One having ordinary skill in the art can, following the teachings herein, use needleless injection devices to deliver genetic material to cells of an individual. Needleless injection devices are well suited to deliver genetic material to all tissue. They are particularly useful to deliver genetic material to skin and muscle cells. In some embodiments, a needleless injection device may be used to propel a liquid that contains DNA molecules toward the surface of the individual's skin. The liquid is propelled at a sufficient velocity such that upon impact with the skin the liquid penetrates the surface of the skin, permeates the skin and muscle tissue therebeneath. Thus, the genetic material is simultaneously administered intradermally, subcutaneously and intramuscularly. In some embodiments, a needleless injection device may be used to deliver genetic material to tissue of other organs in order to introduce a nucleic acid molecule to cells of that organ.

Preferred embodiments concern methods of treating or preventing HCV infection. In these embodiments, an animal in need is provided an HCV antigen (e.g., a peptide antigen or nucleic acid-based antigen, as described herein (**SEQ. ID. NOs.: 1-27**)) and an amount of adjuvant (e.g., ribavirin) sufficient to exhibit an adjuvant activity in said animal. Accordingly, an animal can be identified as one in need by using currently available diagnostic testing or clinical evaluation. The adjuvant (e.g.,

ribavirin) and antigen can be provided separately or in combination, and other adjuvants (e.g., oil, alum, or other agents that enhance an immune response) can also be provided to the animal in need.

Other embodiments of the invention include methods of enhancing an immune response to an HCV antigen by providing an animal in need with an amount of adjuvant (e.g., ribavirin) and one or more of **SEQ. ID. NOs.: 1-11**, or a fragment thereof, preferably **SEQ. ID. NOs.: 12-27** that is effective to enhance said immune response. In these embodiments, an animal in need of an enhanced immune response to an antigen is identified by using currently available diagnostic testing or clinical evaluation. By one approach, for example, an uninfected individual is provided with the vaccine compositions described above in an amount sufficient to elicit a cellular and humoral immune response to NS3 so as to protect said individual from becoming infected with HCV. In another embodiment, an HCV-infected individual is identified and provided with a vaccine composition comprising ribavirin and NS3 in an amount sufficient to enhance the cellular and humoral immune response against NS3 so as to reduce or eliminate the HCV infection. Such individual may be in the chronic or acute phase of the infection. In yet another embodiment, an HCV-infected individual suffering from HCC is provided with a composition comprising an adjuvant (e.g., ribavirin) and the NS3/4A fusion gene in an amount sufficient to elicit a cellular and humoral immune response against NS3-expressing tumor cells.

Although the invention has been described with reference to embodiments and examples, it should be understood that various modifications can be made without departing from the spirit of the invention. Accordingly, the invention is limited only by the following claims. All references cited herein are hereby expressly incorporated by reference.